Transport and the Global Environment: Accounting for GHG Reductions in Policy Analysis

Developed by UNEP Collaborating Centre on Energy and Environment

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Acknowledgements

Abbreviations and Acronyms

AIJ	Activities Implemented Jointly
CC	Climate Change
CDM	Clean Development Mechanism
CH$_4$	Methane
CO	Carbon monoxide
CO$_2$	Carbon dioxide
GEF	Global Environment Facility
GHG	Greenhouse gas(es)
GO	Global overlay
GWP	Global warming potential
HC	Hydrocarbons
HFC	Hydrofluorocarbons
I & M	Inspection and maintenance (programme)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied petroleum gas
N$_2$O	Nitrous oxide
NMHC	Non-methane hydrocarbons
NMVOC	Non-methane volatile organic compound
NO	Nitric oxide
NO$_2$	Nitrogen dioxide
NO$_x$	Oxides of nitrogen
O$_3$	Ozone
OEM	Original equipment manufacture
PFC	Perfluorocarbons
PLS	Pumpless lubrication system
PM	Particulate matter
PTE	Present tonnes equivalent
SF$_6$	Sulphur hexafluoride
SO$_2$	Sulphur dioxide
SPM	Suspended particulate matter
TSEV	Two-stroke engine vehicle
TSP	Total suspended particulates
VOC	Volatile organic compound(s)
WHO	World Health Organisation
ZEV	Zero emissions vehicle

Preface

That the transport sector is among the fastest growing economic sectors in both developed and developing countries is no surprise. The movement of people and goods is an essential part of modern society, and unlike some other economic goods the demand for transport largely coupled to income, so that as people become wealthier they demand ever more transport. Despite their many advantages of personal choice, convenience, and flexibility, modern transportation systems are not without problems, notably those that affect the environment and quality of life. The poor, even hazardous, air quality in many cities is often largely attributed to motor vehicle use, while the transport sector globally contributes one quarter of the greenhouse gases emitted to the atmosphere each year. Unfortunately, the environmental consequences of transportation choices – both local and global – are often overlooked when transport planning decisions are made.

This book attempts to remedy that deficiency by providing a guide to technical experts and policy makers concerned with environmental polices for the transport sector. It offers a consistent analytical structure for examining the environmental aspects of transport choices; defines the key economic and environmental concepts used in good policy analysis; and gives information on technologies, environmental impacts, and cost effectiveness of various policy options. The book also describes international financial mechanisms that can be used to support sustainable transportation policies and programmes.

The methodological framework presented was developed by the UNEP Collaborating Centre on Energy and Environment. Kirsten Halsnaes was the lead economist for the project, and worked closely with Anil Markandya of the University of Bath, UK, and Jayant Sathaye of the Lawrence Berkeley Laboratory, USA. The work was sponsored by the World Bank and by UNEP DTIE as part of the latter's energy and transportation sector programme. UNEP's International Environmental Technology Centre, located in Osaka, Japan, will promote the framework as a tool for good policy analysis in the transport sector.

1. Introduction

1.1 Background

Climate change is now recognised as presenting a potentially substantial threat to fundamental natural and human resources on a global basis. The consequent need for mitigating climate change impacts, through the reduction of greenhouse gas emissions to the atmosphere, is now established as a policy priority by many national governments and international organisations. However, the implementation of such policies is likely to be determined at least in part by the scale of the costs associated with bringing about such reductions. There is therefore a need to identify those measures that are likely to bring about a given reduction in greenhouse gases at the least cost.

At the same time, emissions from the transport sector make up a large and growing proportion of total global emissions, particularly in developing countries. Transport development is viewed as a necessary precursor to wider economic development.

This book has therefore been compiled in response to a perceived need on the part of officials in international funding organisations, donor and recipient governments, and other national institutions dealing with transportation planning to have an outline methodology that helps to identify cost-effective mitigation policy measures in relation to the transportation sector. The methodology that is presented here is an extension of one that has been developed and adopted by the World Bank in relation to the energy and forestry sectors. This volume has arisen out of a research project originally commissioned by the World Bank and carried out by the UNEP Collaborating Centre on Energy and the Environment, with assistance from Anil Markandya (University of Bath) and Jayant Sathaye (University of California).

The methodology, known as "Global Overlays" has been used by the World Bank to evaluate the global externalities associated with the energy and forestry sectors. In essence attempts to identify as a base case the intervention that would have been designed if no attention were paid to greenhouse effects. It then asks what are the extra costs incurred in implementing a "GHG friendly" strategy and determines whether the strategy should be implemented by comparing the implicit cost per tonne of carbon emissions avoided with the equivalent marginal cost for other projects in the same or other sectors. The application of this least-cost methodology to the transport sector is complicated by a number of factors, including the impact on local air pollutants and the complex modelling approaches needed to estimate impacts of policies on emissions from vehicle transport.

The need for methodological development is highlighted by the flexibility mechanisms of the Kyoto Protocol. Under these mechanisms the impact of projects and policy measures needs to be established to gain emissions credits. This book outlines such a methodology, providing case studies that show its application to real world situations. The project and policy recommendations that can be drawn from this methodology are most likely to be implemented if external funding is made available. The possibilities for such funding through the planned operation of the flexibility mechanisms of the Kyoto Protocol, the Prototype Carbon Fund and Global Environment Facility are therefore also outlined in this volume.

1.2 Structure

Local environment and development perspectives are prevalent in the transportation sector, in addition to global concerns raised by climate change. Therefore, implementation of GHG reduction inclusive policies in the transport sector requires new analytical and conceptual approaches, which are presented in Chapters 2 and 3.

When conducting analysis of GHG reduction inclusive policies, cost concepts need to be used in order to assess the value of the resources that may be invested in meeting the policy objectives. The costs of these activities to society comprise both external and private cost, collectively defined as social cost. Of particular importance to climate mitigation is the concept of incremental cost, for which GEF funding may be available. This concept is discussed in Section 3.2.5.

These cost concepts can be used to conduct analysis of transport policies, and their impact on GHG emissions, through the use of cost effectiveness analysis. Cost effectiveness analysis is fundamentally concerned with finding the least cost, or most efficient, way of achieving a predetermined goal, e.g. a given reduction in emissions of a targeted pollutant or the policy package that yields the greatest net benefit. Alternatives to cost effectiveness analysis include cost-benefit analysis and multi-attribute analysis. In contrast to CBA, CEA does not require that the project or intervention's output be expressed in monetary terms. Where the benefits of a given project are uncertain or unquantified, as is the case with mitigation policies, CEA may be used to achieve a given reduction at least cost. Abatement cost curves can be constructed using either partial solutions, the retrospective systems approach or the integrated systems approach in order to aid policy analysis. Within CBA, different measures of a policy or project's impact exist: the net present value, the benefit-cost ratio and the internal rate of return. The net benefit investment ratio facilitates project proposal ranking in the case of limited capital funds. These approaches are discussed in Section 3.3.

No-regrets options may exist where a project or policy achieves its stated objective with no incremental cost. Such cases may be particularly true when secondary or ancillary benefits are taken into consideration, which are discussed in Section 3.2.6. However, implementation or hidden costs may exist that would hinder such projects. Implementation costs include administration costs and barrier removal costs, and these should be taken into account in project analysis of mitigation-related projects in the transport sector (Section 3.2.7).

Discounting of future costs and benefits is an important issue in the context of the climate mitigation debate. The choice of discount rate has both economic and political significance, with the consequence being that sensitivity analysis using different discount rate is often conducted to better inform policy makers. Another important issue related to the time dimension is that of the need to forecast future costs and the consideration of price changes over time.

Chapter 4 addresses issues relating to the implementation of GHG mitigation policy in the transport sector. GHG mitigation in the transportation sector may be implemented as a part of cross-sectoral programmes designed to support local development and environmental policies. In this case potential GHG emission reduction projects must be considered explicitly in the context that the GHG reductions necessitate trade-offs

with these other priorities. Local benefits of transportation sector urban air pollution control programmes are likely to be large. Therefore, local governments may wish to combine the development of such programmes with GHG reduction strategies in order to secure international climate finance that enables both local and global benefits to be realised. Thus, international climate change finance may act as a subsidy in the attainment of other national policy goals, though it should be noted that such an approach generally will not lead to the most cost-efficient regulation from a national or global point of view.

Chapter 5 presents case studies of the use of the conceptual framework in relation to transport reform in developing countries. Benefits from reducing local pollutants are examined in addition to GHG reduction benefits.

The main environmental impacts of motor vehicles primarily relate to the effect of air emissions on health and the environment. These are discussed in Chapter 6. The transport sector is a growing source of greenhouse gases, including carbon dioxide, methane and nitrous oxide. Direct health risks for humans from emissions are most common in urban areas, are local to the source and result from emissions of particulate matter, lead, carbon monoxide and toxic hydrocarbons. Such health risks tend to dominate air pollution related damages from transport. In addition, the transport sector can be linked to impacts such as noise, vibration, ecological damage, resource use, congestions and accidents. All of these impacts impose a cost on society.

Various technological options exist for reductions in GHG emissions, and these are discussed in Chapter 7, along with planning options. A vast array of technical options exists, including the use of alternative fuel sources such as ethanol, LPG and CNG. The application of such measures to the developing country context depends on a number of critical implementation issues, including infrastructure and cost, but the range of technical and planning options suggest that standards and economic instrument approaches to GHG integrated reduction policies have much future potential.

A number of new technologies are in development, including fuel cells, which at present are not economic to implement. However, future developments should significantly reduce the cost of these. In addition, options exist for the improvement of vehicle efficiency, both through improved design of new vehicles and retrofitting of in-service vehicles. Potential improvements include reducing aerodynamic drag, rolling resistance and weight of vehicles, all of which have implications for fuel economy and hence emission of GHG and local pollutants.

On the planning side, transport supply management (TSM), including measures to manage capacity, throughput and flow, offers much potential for reduced emissions. In addition, transport demand management strategies (TDM) offer ways of increasing travel choice and changing incentives for the use of less polluting modes of transport. Targeted commuting, which balances peak period travel, is one such technique, as is the introduction or improvement of public transit schemes.

Land use planning can also be used as a mechanism for reducing transport demand and hence GHG emission. Zoning, increased density of population and the physical

layout of residential property may all reduce transport demand. In bringing such measures to fruition, regional transport agencies may be effective, as they have been shown to be in Brazil, Singapore and Hong Kong.

A range of economic policy instruments may be introduced in order to bring about GHG reduction objectives, and these are discussed in Chapter 8. The choice of instrument is likely to be determined by a number of factors relating to their relative flexibility, their costs, the degree to which they guarantee a certain level of GHG reduction and the distribution of their associated benefits and costs. However, the complexity of this decision will be exacerbated significantly by the fact that the reduction of GHGs will be only one objective amongst a number of other social, economic and environmental objectives that a typical transport policy programme is likely to want to pursue.

As a result of this complexity we suggest that it is of paramount importance that in the evolution of any such programme all relevant ministries and other stakeholder groups be well versed in the trade-offs that are associated with individual, or combinations of, policy instruments. Thus, the trade-offs entailed should be described as clearly and, where possible, in quantitative terms for there to be clarity in the subsequent negotiations.

Issues relating to the financing of transport sector GHG reduction inclusive policies are addressed in Chapter 9. The chapter outlined three mechanisms that appear to support the possibility of financial assistance to transport projects that incorporate GHG reduction objectives. Global climate change policy, currently shaped by the structure of the Kyoto Protocol, appears to offer the opportunity of support to such projects through its JI and CDM flexibility mechanisms, once the Protocol is ratified. The Prototype Carbon Fund is a World Bank administered resource to support pilot JI/CDM-type projects prior to Protocol ratification that may support transport projects in the meantime. Finally, the GEF Operational Programme 13 is a support programme specific to a relatively narrowly defined range of transport project types.

The level of financial assistance to the transport sector that will be forthcoming from the Kyoto-type mechanisms is very uncertain. It is not yet clear what the scale of potential support from these mechanisms is likely to be over time since the mechanisms are still evolving prior to Protocol ratification. Ultimately, however - and assuming ratification does proceed - it seems likely that the take-up by the transport sector is not going to be determined so much by the technical demands that this sector makes in establishing emission reduction levels, but by the cost effectiveness of these projects compared to those in other sectors.

Chapter 10 highlights the possibilities for funding organisations can take advantage of the wide variety of mechanisms to encourage public-private sector collaboration that already exist at national and international levels. Opportunities for private sector collaboration in GHG reduction inclusive programmes can therefore be encouraged in the most cost-effective manner. Introducing new mechanisms could be easier if funding organisations exploit networks of private sector producers maintained by international industry associations. Finally chapter 11 presents some case studies of examples where public-private sector collaboration has been used.

2. Analytical framework

2.1 Decision making framework

2.1.1   Overview

The need to consider the reduction of greenhouse gas (GHG) climate change externalities as an objective of transport policy analysis highlights the increased importance placed on global concerns about climate change. To date, guidelines have been developed for the inclusion of GHG externalities in the energy and forestry sectors (World Bank, 1997). This book presents guidelines for the transport sector.

The use of the term "GHG externalities" itself suggests that economic and sectoral policy considers GHG emission reductions as a secondary impact of policy programmes. GHG emission reduction policy analysis is based on the marginal costs and benefits of integrating GHG mitigation options into project/sector work. It is hoped that having achieved this integration, transport sector policy could be targeted towards meeting transportation needs with an acceptable level of associated GHG emissions. Responding to this challenge, however, requires us to define an acceptable level of associated GHG emissions.

One key objective of this book is to enable practitioners to extend their sectoral work by including GHG emission impacts and possible GHG mitigation analyses. The book therefore provides useful guidance for including GHG externalities in economic analyses of projects when (a) payments related to the project are made under international agreement, or (b) project and sectoral components are financed by the Global Environment Facility (GEF) .

It is important to recognise that some transportation activities result in increased GHG emissions compared with a baseline case, when the baseline case is defined as the business as usual case without intervention. Examples of activities that increase GHG emissions are infrastructure programmes such as highways and railways, and urban mass transit systems that lead to increased transportation. Efficiency improvements in existing transport systems, such as the introduction of more reliable and efficient buses, may also lead to increased energy consumption and GHG emissions, if the activity increase outweighs the achieved unit emission savings (essentially trading off increases in an "activity statistic" with decreases in an "emission factor"). Several specific issues in measuring the GHG emission impacts of transportation programmes are discussed in Chapter 4 of this book. This chapter prefaces the evaluation of alternative rules for measuring GHG emission reductions related to GHG reduction "inclusive" policies.

It should also be noted that transportation programme policy objectives are often attainable using several technologies or other options with various associated GHG emissions. A key objective of GHG reduction "inclusive" transport policies is therefore to identify cost-effective emission reduction strategies that both are in line with the general objectives of the transportation programme and that fulfil the eligibility criteria for international climate finance.

2.2 General structure of the methodological framework

In this section we outline the analytical structure of the assessment of GHG reduction inclusive policies, including the main analytical steps, approaches and tools, as well as data inputs. The analytical structure is illustrated in Figure 2.1.

Figure 2.1   Analytical structure
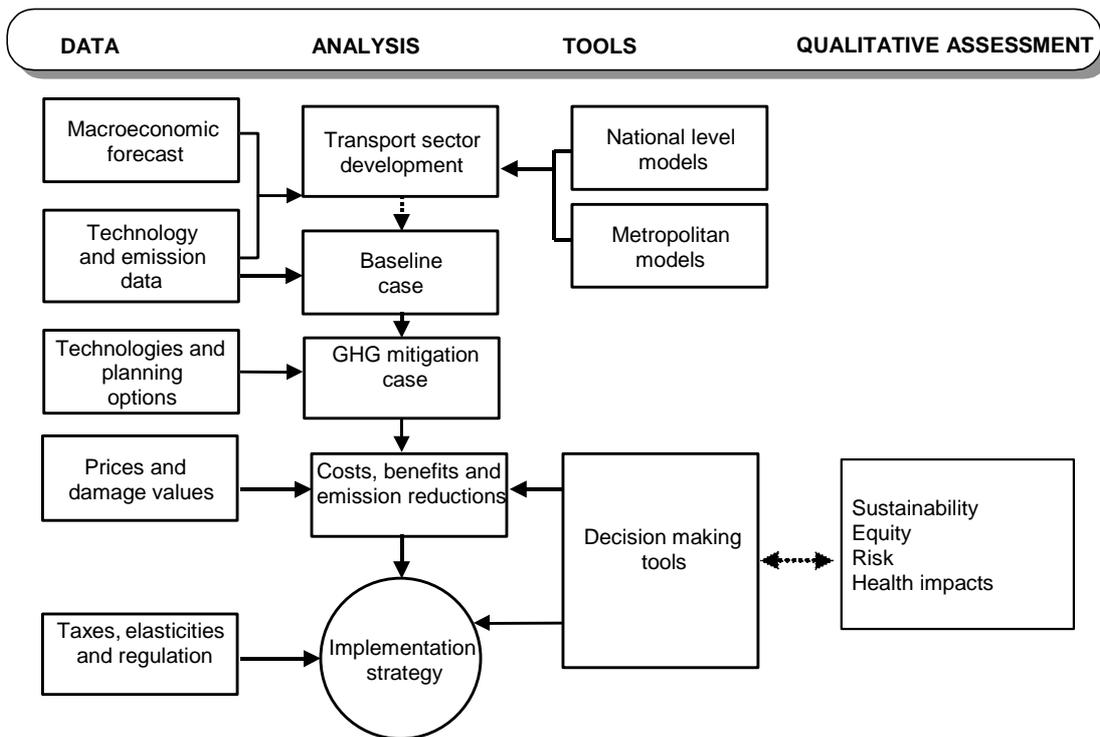
The second column of Figure 2.1 includes the following five steps of the analytical structure:

Step 1: Evaluate transport sector development trends

The purpose of this step is to provide a general overview of GHG emissions from the transportation sector based on available macroeconomic forecasts and technology information, already available sectoral planning documents and GHG emission inventories. This information will serve as a background for the subsequent, more detailed study of policy options.

Step 2: Define Baseline case specific to the GHG reduction inclusive project

This step constructs a detailed definition of a baseline case, which will be used as a reference point for the GHG reduction inclusive policy case. This second analytical step is related to step one, but illustrated with a dotted line in Figure 2.1 to emphasise the soft link between them. Step two should be consistent with the overview provided in step one, but is not directly derived from step one (as that would make the baseline case definition too detailed an exercise).

Step 3: Define a GHG reduction inclusive policy case

The GHG reduction inclusive policy case is defined in this third step as a policy that integrates GHG externalities into the baseline case established in step 2. Such a case, outlined below, can either be an adjustment of transportation policies designed without considering GHG externalities, or comprise of transportation policies that integrate GHG reduction policies at an early phase of the programme design. This step requires data about technologies and other planning options.

Step 4: Assess GHG emission reductions, costs, benefits and other impacts of the GHG reduction case

This step includes an assessment of GHG emissions, costs, benefits and other impacts of the policy defined in step 3. It may require generating monetary information, other physical information and qualitative information. This information would be selected and established on the basis of national priorities related to transportation policies, environment and other broader development objectives. The information will be analysed using different decision tools such as cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) or multi-criteria analysis (MCA).

Step 5: Assess implementation strategy and identify policy instruments where relevant

The final step seeks to assess the implementation strategy for the GHG reduction case and is likely to include an evaluation of alternative policy instruments such as market-based instruments and regulatory options, with the focus being on relative implementation costs, as well as on barriers to implementation.

Note that the formal assessment of GHG reduction inclusive policies includes only steps 2 through to 5, but that step 1 more generally aims to provide a broad overview of transport sector development and GHG emissions within which policies are to be formulated.

The principle underlying this broad analytical framework for GHG inclusive policies is to establish a consistent framework for integrating information from various planning activities, data sources, modelling tools and decision-making tools. This book focuses on defining key concepts used to evaluate the costs and benefits of integrating GHG externalities into transportation policies, building on established analyses in transport sector research.

Various tools and approaches support the policy analysis, including sector models, macroeconomic models, cost-benefit analysis, and detailed technology assessments. This book explains how these tools and approaches may be used with the five analytical steps outlined above.

2.3 GHG reduction inclusive policy options

2.3.1   Main structure of the framework

In principle, GHG reduction inclusive policy options may address a single, or all, components in "the transportation activity - GHG emissions chain", including policies designed to influence the volume of transportation activity, modal structures, individual vehicles or fuel systems. Assessing policy interventions at these different levels is outlined in the ASIF methodology (**A**ctivities, **S**tructure, **I**ntensity and **F**uels) (Schipper and Marie-Lilliu, 1999).

The structure of the transportation–GHG emission chain is illustrated in Figure 2.2. Note that Figure 2.2 should be read from the bottom upwards.

Figure 2.2 Structural Relationships Between Transportation Activities and GHG Emissions
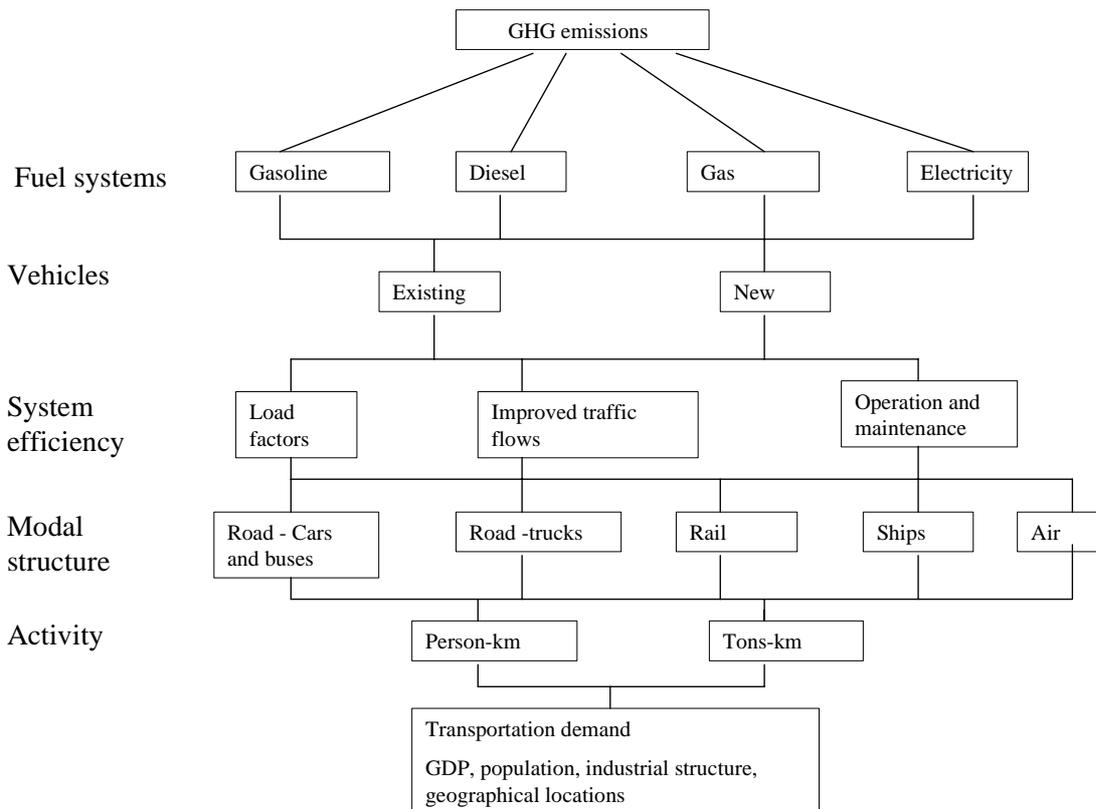
Figure 2.2 shows that transportation *activity* arises out of demand for transportation services and can be explained by general macro-economic indicators, such as GDP, population, industrial structure, and geographical location. Transportation *activities*

may be separated into person-transport (expressed in person-km) and freight-transport (expressed in tons-km). Next, the *modal structure* of *activities* can be split into the following categories; cars, buses, trucks, rail, ships and air. The *system efficiency* of these modes can then be assessed, considering load factors, improved traffic flows, inspection and maintenance (I & M), etc. towards the goal of improving the overall modal efficiency. Potential efficiency improvements are subsequently assessed in greater detail for individual *vehicles*, which are typically separated into existing and new vehicles.

The principal output of the *system efficiency* and *vehicles* phases of analysis is a projection of the total energy consumption for individual vehicles of specific mode and vintage. Following this, GHG emissions resulting from the estimated energy consumption are calculated in the *fuel system* step; the energy consumption is split into gasoline, diesel, various sorts of gas and electricity (that is, divided into primary fuels).

2.4 Decision criteria for initiation of transport projects

To be acceptable on economic grounds, a project must meet two conditions:

- The expected net present value of the project must not be negative.
- The expected net present value of the project must be higher than or equal to the expected net present value of mutually acceptable project alternatives.

The specific additional GHG mitigation costs should be regarded as an additional project cost that should be financed with specific funds. For example, the Global Environment Facility (GEF) will provide new and additional grant and concessionary funding to meet the agreed incremental costs of measures to achieve identified global environmental benefits as defined for specific options in the GEF Operational Programme 11. The GEF will also provide funding for the removal of barriers to the implementation of GHG-friendly technologies.

For some projects, physical measures of achievement in relation to costs (i.e. cost-effectiveness) are appropriate. In other cases, such as institutional reforms, a qualitative account of the expected net development impact might have to suffice. In all cases, however, the economic analysis should give a persuasive rationale for why the benefits of the project or policy area are expected to outweigh its costs – in other words, why the net development impact of the project or policy is expected to be positive.

The inclusion of GHG reduction as a policy objective adds complexity to transport policy environmental assessments because the policy's environmental objectives have been expanded to include a number of new "performance" indicators, which are represented by the GHG emissions. These performance indicators include: CO_2, CH_4, N_2O, HFC, PFCs and SF_6. These can be converted into CO_2 equivalent units using Global Warming Potential (GWP) values.

As outlined above, for a project or policy to be accepted it should have a net positive impact on development. Cost, environmental, development and other impacts that are

considered to be key decision criteria must be defined for each transportation activity under consideration. Primary decision criteria include project costs, local environmental impacts, social impacts and GHG emissions. The donor organisation and implementing countries may have different interests regarding policy impacts and priorities. A number of issues involved in establishing a "balanced" project portfolio are discussed in more detail in Chapter 4.

The objective of including GHG reduction as a potential policy objective is to integrate GHG externalities into transport sector analysis. To assess the costs and benefits of meeting global objectives, specific projects need to be assessed in relation to a baseline case[1], reflecting the difference in outcomes between inclusion and exclusion of the GHG reduction as a policy objective. Such a baseline case can be defined in several ways, the choice having important implications for the outcome of the policy evaluation. A more detailed discussion of these issues is given below.

2.4.1 Analytical approaches

Various analytical approaches may be used in analysis of GHG reduction inclusive policies where multiple decision criteria and impacts are assessed. These approaches include cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA). They are outlined in and presented in detail in Chapter 3.

The central differences between these three approaches stem from the ways in which the objectives (i.e. the decision parameters) of the decision-making framework are selected, specified and valued (Halsnæs et. al. 1998; IPCC 2001b, chapter 7). Examples of these objectives are costs, benefits, regional environmental impacts, and GHG emissions. These objectives may be specified in economic (monetary) units or in physical units such as the amount of pollutants dispersed (e.g. tonnes of CO_2), and Chapter 3 explains how these cost assessment approaches may be used to evaluate the cost effectiveness of transport related GHG reduction inclusive policies. The physical indicators and monetary terms may be supplemented with qualitative information.

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[1] The baseline case is elsewhere referred to as the reference case (World Bank, 1997).

Box 2.1 Analytical Approaches

Cost-benefit analysis
CBA measures all negative and positive project impacts as monetary costs or benefits. In the case of GHG emission reduction studies, all costs of implementing a given strategy are compared with the benefits of implementing the strategy, as well as with the benefits of reduced climate change damages. Determining the value of reduced climate change damages is difficult and uncertain; therefore it might be appropriate to use cost-effectiveness analysis instead of CBA.

Cost-effectiveness analysis[2]
CEA is a special sort of CBA, in which all the costs of a portfolio of projects are assessed in relation to a policy goal, which is expressed in physical units. The policy goal in CEA represents the benefits of the projects and all other impacts are represented as either positive or negative costs. (Negative costs, with the exception of the policy goal, may correspond to all other benefits of the policy). The policy goal may, for example, be a specific reduction in GHG emissions. In such a case, analysis results may be expressed as the net costs of GHG emission reductions (in $ per tonne). .

Multi-criteria analysis
MCA defines a framework for integrating various decision parameters and values in a quantitative analysis without assigning monetary values to all parameters. Examples that are controversial and very difficult to measure non-monetarily include human health impacts, equity, and irreversible environmental damages. In short, MCA uses non-monetary decision factors with decision factors expressed in money terms.

Another analytical approach used to assess GHG reduction-inclusive projects is a "back casting exercise" in which a carbon shadow price is applied to carbon emission estimates of energy project environmental damage costs (World Bank, 1998a). This approach is similar to CBA in that it assigns monetary values to carbon emissions as a proxy for climate change damages. The damages are valued by reviewing of international climate change impact studies. A "back casting exercise" is conducted to reveal carbon switching values that are given by the net present value of the project, divided by the net present value of resultant carbon reductions (yielding a measure of costs per t of C reduction)[4]. All carbon switching values of equal or lesser value than the shadow price of carbon will then have a positive benefit/cost ratio, and thereby fulfil the first part of the general decision criteria required of projects. According to these criteria the projects also should have an equivalent or higher net present value, compared to alternative projects. From a GHG mitigation perspective this means that the carbon switching value should be as low as possible.

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[2] The term cost-effectiveness analysis is sometimes used in more narrow way, where only the financial costs - and no indirect positive and negative costs - of a private agent in meeting a specific policy goal are considered.

[3] The term cost-effectiveness analysis is sometimes used in more narrow way, where only the financial costs - and no indirect positive and negative costs - of a private agent in meeting a specific policy goal are considered.

[4] This decision criteria is the same as applied in a cost-effectiveness analysis.

2.5 Baseline cases and GHG reduction inclusive policy cases

In order to analyse the global impacts of transportation activities, the changes in GHG emissions resulting from transportation activities that have been designed <u>without</u> taking the GHG reduction objective into consideration need to be compared with the changes in GHG emissions <u>with</u> integrated transportation and GHG reduction policies. A reference, or baseline, case therefore needs to be constructed along with a policy case.

GHG reduction inclusive policies for the transport sector are defined as *policies selected and designed to meet general transport policy objectives as well as global environmental policy objectives*. Concurrently, these policies may address a number of other environmental externalities such as urban air pollution. Collectively, this creates a very complex policy case in which multiple objectives relating to transportation needs, and global, regional and local externalities appear simultaneously, and can represent either joint benefits or trade-offs. Calculating the costs/benefits of the GHG reduction inclusive policy is shown in Box 2.2.

Box 2.2: Calculation of costs/benefits of GHG reduction inclusive policies

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Additional costs = total cost of GHG reduction inclusive policy case *minus* total cost of Baseline case

and

Additional benefits = total GHG emissions under the GHG reduction inclusive policy case *minus* total GHG emissions under the Baseline case

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We can distinguish between two types of GHG reduction inclusive transportation policies:

Case 1. Primary decision criteria are the transportation objectives, with feasible options selected on that basis. GHG mitigation differences, however, are assessed before final project implementation. Additional costs of GHG reduction inclusive programmes are permitted, but not as a "trade-off" with the transportation policy objectives. In such a case, GHG reduction is treated as a secondary decision criterion.

Case 2. Again, primary decision criteria are the transportation policy objectives, but feasible options include GHG reduction inclusive programme options. Mitigation is treated as a primary decision criterion along with transportation policy objectives, and in some cases with regional and local environmental policy objectives.

In principle, both cases may be assessed in relation to different baselines. One category of baseline case is the "business as usual" case, which reflects current development trends, including already implemented economic policies and sectoral programmes. Another possible baseline case is the "transport reform (or

economically efficient) scenario"[5] (World Bank, 1997). Definitions of these two baseline scenarios are provided in Box 2.3 below. See also the discussion in Christensen, Halsnæs and Sathaye (1998) on alternative approaches to baseline case definition. The best sources of information to use in the construction of the baseline cases are national development plans and transport sector plans.

Box 2.3: Baseline scenario approaches

Business as Usual (BAU) Baseline case. Expected development trends in transportation activities given national economic and sectoral policies, with no external intervention.

Transport Reform (or economically efficient) Baseline case. Expected development trends are assumed to take place in planning work conducted as part of a reform programme. This baseline case explicitly assumes the implementation of economic efficiency programmes

Given the range of scenario definitions outlined above, four different contexts in which to compare scenarios are suggested and illustrated in Box 2.4.

Box 2.4: Structure for scenario comparison

Baseline case	**Policy Case 1: Mitigation secondary decision criterion**	**Policy Case 2: Mitigation primary decision criterion**
Business as usual	Policy Appraisal Context 1	Policy Appraisal Context 3
Transport Reform	Policy Appraisal Context 2	Policy Appraisal Context 4

Comparing Case 1 and the Business as Usual baseline represents a policy context in which a transportation programme is designed with GHG mitigation as a secondary decision criteria, in a country where major economic efficiency programmes are not currently implemented. It is different from policy appraisal context 2, where Case 1 is assessed in relation to an economically efficient transport reform baseline case. Here, it is to be expected that programmes, including transportation activities, are currently being introduced in the country in question, and the GHG reduction-inclusive policies therefore will take the form of small adjustments to these policies.

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[5] Such a scenario was considered in World Bank (1997) which considered a "Bank Reform scenario". This scenario explicitly considered the implications of economic efficiency programmes recommended by the World Bank.

Case 2 similarly can be compared to a Business as Usual Baseline case or to a economically efficient transport reform Baseline case. In the first instance, the policy appraisal context (3) is one in which an integrated GHG mitigation and transportation programme comprises part of a proposed initiative. Alternatively, the same case, if compared to an economically efficient baseline case, will be constrained in some way by planned reform activities.

A programme in the transportation sector will often generate increases in activity and therefore GHG emissions as a result of economic development or better infrastructure. This growth, in turn, increases demand for transportation services, which means that economically efficient baseline cases, as well as different sorts of GHG reduction programmes, may suggest higher absolute GHG emissions than a Business as Usual baseline case. GHG emissions related to the programme, however, still may be smaller than what they would have been if the GHG mitigation objective had not been integrated in the transportation programme from the beginning. In this case it may prove more useful to assess the programme in relation to both the Business as Usual baseline case and the economically efficient baseline case.

2.5.1   *Project, sector and economy-wide Baseline case approaches*

Either of the two baseline cases may be defined at the economy-, sectoral-, or project-wide level. Economy-wide baseline approaches are referred to as "top-down", while sectoral- or project level approaches are commonly referred to as "bottom-up". An economy-wide baseline case will require a projection of national economic activity, assuming GHG reduction is not a policy priority. This case may most accurately be generated by a computable general equilibrium (CGE) model. A sectoral level baseline case requires a projection of activity for a given sector, and may be constructed with a partial equilibrium economic model. Finally, a baseline case will often describe a specific transport technology project only, allowing more detail to be included in the analysis. Under a specific GHG reduction inclusive policy case, low GHG (e.g. diesel) buses might be substituted for gasoline buses, requiring projections of the running costs and emission levels of existing gasoline buses to develop the baseline case. These two alternative technologies are well known and the uncertainties in the definition of the baseline case and policy case therefore are primarily due to the more vague assumptions about the use of the buses, the economic lifetime of the vehicles, fuel prices, etc.

It should be noted that some GHG reduction inclusive policies can be expected to have impacts beyond the individual project level. An example of such a policy is the construction of a highway for interregional transport. Such a highway is likely to induce substitution effects between existing transportation activities including railway, buses, cars, trucks, waterways and air, where relevant, whilst also resulting in a general increase in transportation activities. This, in turn, may induce spillover and feedback effects throughout the economy. The baseline case for this project therefore must reflect developments in the general transport sector, as well as economy-wide trends reflecting patterns in capital investment, national and international trade, and secondary impacts on employment, income and industrial siting. The establishment of baseline cases at sectoral and economy-wide levels is, as stated earlier, complex and thus susceptible to many basic uncertainties.

GHG reduction inclusive policies may consider the implementation of an individual policy or may be part of a more comprehensive transportation strategy that includes several policies and options. Clearly, the more options and policies in the transportation and GHG reduction inclusive program, the more likely it is that transportation system impacts and economic consequences will spill over, requiring the establishment of a baseline case at the sector and/or economy-wide level.

2.6 Relationship to FCCC/GEF incremental costs concepts and additionality issues of the CDM

The GHG reduction objectives of sectoral programmes comprise one element of many ongoing international activities aimed at reducing GHG emission reductions in different parts of the world. It is therefore worth outlining at this point how the technical components of this element fit in the wider context of climate change policy development. Further detail on this issue is given in Chapter 9.

Since the establishment of the UNFCCC in 1992 the international community has held extensive discussions on the term "incremental costs" and related baseline case definition issues. Article 12, 5b of The Kyoto Protocol, which addresses the Clean Development Mechanism (CDM) for example, states that emission reductions may be certified by Annex I parties when they are "additional" to any that would occur in the absence of the certified project activity.

The "incremental cost" concept and the "additionality" concept are related. Incremental costs focus on the cost of implementing GHG limitation policies compared to a baseline case, while additionality, as outlined in the Kyoto Protocol, is assigned to emission reductions, which in turn are expected to raise costs compared with the baseline case. These costs, like the emission reductions, may be referred to as "additional costs". When the incremental cost and additionality terms are understood in this way the concepts are quite similar[6]; both rely on the comparison of a policy case and a baseline case.

Note that the additionality term has been used somewhat differently in international discussions on the financial costs of GHG emission reduction policies. A group of non-Annex I countries states that *financing* emission reduction projects through the CDM, like the emission reductions, should be "additional". Therefore it is important to distinguish "emission additionality" from "financial additionality". Emission additionality relates to activities that the CDM project substitutes, while financial additionality relates to other projects in a country that could have attracted financing instead of the CDM project. Such "alternative" projects include a broad range of capital investments, and are not limited to issues of climate change[7].

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[6] Despite similarities there can potentially be some different interpretations of the incremental cost and the additionality concept primarily originating from the actual specification of the incremental costs in the Operational Programme of the Global Environment Facility.

[7] It is very difficult to define a baseline case for financial additionality, because this should reflect a forecast of all alternative financial projects.

2.7 Methodologies for inclusion of GHG reduction in project analysis

2.7.1   Relationship to Transport Sector Work and Environmental Programmes

As outlined in Section 2.1.1, the application of GHG mitigation policies to the transportation sector essentially adds a further objective to ongoing transportation activities. However, it is desirable that the methodology used to evaluate multiple objectives be a parallel extension of those techniques already in use in policy appraisal in the transport sector. This process of parallel analysis has already been developed in the two large policy areas related to the transport sector of infrastructure investments and urban air quality programmes. These activities are described and discussed in a special report on sustainable transportation (World Bank, 1996). Case studies presented in Chapter 5 show how such policies may be integrated in studies. The case studies address potential synergies, trade-offs and conflicts between global and local environmental policies, which, for example, have been discussed in relation to urban air pollution control programmes (see Eskeland and Xie, 1998).

2.7.2   Relationship to World Bank Global Overlays Programmes

In 1997 the World Bank Environment Department issued Guidelines for Climate Change Global Overlays for the energy and forestry sector (World Bank, 1997). These Guidelines established a broad methodological framework, drawing on the concept of "global overlays", for sectoral assessment. The global overlay concept, while fairly flexible, can be defined as an approach in which GHG externalities are integrated into economic and sector work. The methodological framework suggested in this study aims, as far as possible, to be consistent with that developed for energy and forestry for the World Bank.

2.7.3   Relationship to Sustainability and Broader Social Issues

Sustainability issues relating to transport sector development were discussed in World Bank (1996). This study examines how sustainability – broadly defined –can be the basis for a more demanding transportation policy.

Sustainability is defined here as *economic and financial sustainability, environment and ecological sustainability* as well as *social sustainability.* The baseline case section in these Guidelines addresses the question as to how using quantitative and qualitative information specific sustainability issues may be included as part of an analysis of GHG reduction inclusive policy measures.

3. Conceptual framework

3.1 Introduction

This chapter provides the conceptual framework for the assessment of GHG reduction inclusive projects, including the economic concepts of cost, and the associated decision-making rules that utilise the cost concepts. It consists of two parts, the first of which defines the main cost concepts underpinning the economic analysis of transport sector GHG mitigation. A distinction is made between private, generalised, and social costs, and between economic and financial costs. Project cost categories relevant to transport sector GHG mitigation are then examined. The second part shows how these cost concepts are used to make decisions about projects and policies, specifically, the mechanics underlying cost-effectiveness analysis – the primary criterion for selecting optimal strategies for dealing with the transport-environment nexus. Cost-benefit analysis is also described, along with detailed examples of its application. Finally, inter-temporal issues are discussed, including discounting and forecasting changes in prices.

3.2 Cost Concepts in Transport Policy Economic Analysis[8]

3.2.1 *Distinction Between Private (generalised) Cost and Social Cost*

A basic distinction in all cost work is between what economists refer to as the **social cost** and the **private cost** of an activity. The latter refers to costs typically taken into account when making everyday decisions. Private costs are derived from the market price of goods and services. Such costs are private in the sense that they are internal, and have a direct influence on, to the individual's private decision-making process.

When deciding on travel behaviour however, individuals do not choose between modes of transport solely on the basis of market prices. In addition to "out-of-pocket" costs – e.g. the price of gasoline or diesel, vehicle operation and maintenance costs, the price of alternative travel modes, etc. - individuals consider other factors, such as time taken and convenience. Economists therefore distinguish between private costs (based purely on market prices) and **generalised costs** when appraising transport projects. The latter refers to the total cost paid to use a mode of transport, primarily consisting of "out-of-pocket" expenses and the value of time taken[9]. Table 3.1 below illustrates the concept of generalised cost.

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[8] The content of this section is partly based on material presented in Markandya and Halsnaes (1999) "Costing Methodologies".

[9] When deciding whether to travel or not to travel, or which mode to use, travel time is an important factor considered by individuals. Hence, the valuation of time costs/savings is common practice in the economic evaluation of transport projects. See, for example, MVA and TSU (1994) for a technical discussion of the valuation of time.

Table 3.1 The Concept of Generalised Cost Used in Auto Oil II

Components of generalised cost	Illustrative value
1. Cost of supplying transport service	200
2. Tax	40
3. Market cost [= 1 + 2]	240
4. Travel time (= time travelled x unit value of time)	30
5. Generalized cost [= 3 + 4]	270

Source: Adapted from DRI, KUL and IFP (1998).

Clearly, generalised costs play a significant role in the selection of transport programmes and projects. Faced with a portfolio of possible programmes, the decision-maker will typically consider the initial investment requirements, comprising actual expenditures on raw materials, capital equipment and its installation, and annual expenses on labour, energy and consumables, time costs/savings, etc. These items are priced in the marketplace (with the exception of time), so are internal to the decision-making process, in that they influence programme choice.

The generalised costs of a decision (e.g. to undertake one transport programme over another) however, do not necessarily reflect all the costs that this decision imposes on society. Transport activity produces impacts that adversely affect human welfare, including the impairment of human health and ecological functions, congestion, noise pollution, the obstruction of views, etc. More often than not, these "environmental" impacts are not taken into account in the decision-making process, in which case they are referred to as externalities. That is, the cost of such effects is external to the decision-making process[10].

The term **external cost** is used in economics to define those costs arising from any human activity not accounted for by the agent causing the externality. For example, particulate emissions from motor vehicles affect the health of people exposed to the pollution, but this might not be considered, or might be given inadequate weight by users of the motor vehicles when making decisions about their usage. Air pollution, in this case, is referred to as an **externality**, and the costs it imposes on human receptors are referred to as **external costs** (i.e. the adverse human health effects).

When these costs are external to the decision-making process, scarce resources (financial and otherwise) will not be allocated efficiently among the portfolio of available transport projects – that is, they will not be allocated to yield the greatest "good". This is particularly relevant to transport sector project selection, where multiple policy objectives and external effects are normal. Situations are likely to arise, for example, in which one set of air pollution limitation measures represents a least-private-cost solution to a particular policy objective, but the composition of the "optimal" set changes as the basis of the cost-effectiveness analysis shifts from

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[10] The internalisation of external costs into the individual's decision-making process is an issue for governments. In recent years efforts to reduce the externalities involved in transport have included the raising of taxes on fuels, the prohibition of certain fuels and investment in public transport (in an effort to remove private passenger cars from urban areas). The concept of social cost is thus an important one in the transport policy debate.

generalised costs to social costs[11]. These circumstances may arise when the measures considered are relatively more effective at abating the target pollutant, but perform poorly in terms of other environmental impacts and objectives.

The full cost of an activity to society comprises both the external cost and the generalised (private) cost, collectively defined as the **social cost**. If society's scarce resources are to be used to maximise social utility, then decisions governing resource allocation should, to the extent possible, be based on social costs:

Social Cost = External Cost + Generalised (Private) Cost

The environmental impacts of transportation systems giving rise to external costs are examined in the next chapter. External cost estimation is carried out using a number of methods discussed in detail elsewhere. For a practically oriented book on external cost estimation, see Markandya *et al* (2001). External costs for the transport sector have been estimated by Maddison et al (1996) and European Commission (2000).

In summary, a transport sector cost analysis may be performed with generalised costs or social costs, or with some combination of the two. However, in order to ensure that scarce resources are allocated efficiently among the portfolio of available transport projects (i.e. to yield the greatest "good"), analysts should, to the extent possible, work with social costs.

3.2.2   *Distinction Between Economic (Opportunity) Cost and Financial Cost*

In addition to the distinction between generalised (private) cost and social cost, it is often necessary in economic analysis to further distinguish **economic cost** from **financial cost.** A good's economic cost is the full value of the scarce resources used to it. These resources, in turn, are measured in terms of the value of the next best thing, which could have been produced with the same resources (i.e. the value of the opportunity foregone), the term **opportunity cost** is used to describe such costs.

This notion of cost differs from the accounting notion of cost. For example, in estimating the cost of running a light rail transit system through a tract of public land, how should the analyst calculate the land's cost? In some cases, a zero 'cost' is attached, because the land is not rented out so no rent money flows to the owner. Economic cost values the land according to the value of the output that would have been received from that land, had it not been used for the light rail transit system. The

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[11]   As illustrated below, working with social costs does not exclude the use of cost-effectiveness analysis as a policy selection tool.

land's output may be a market good or service (e.g. agricultural output), and/or a non-market good or service (e.g. recreational use). When valued in this way, the cost of the land is given by its "**opportunity cost**." A transport project resource input's opportunity cost is the measure of cost used. Given that we are interested in the opportunity cost, we must know how to measure it. The measure of opportunity cost is the minimum payment that the resource owner is **willing to accept** for its use, or the maximum a consumer of the resource is **willing to pay** for its use (WTA and WTP, respectively). For a discussion of the difference between WTP and WTA see Markandya et al (2001).

3.2.3 Shadow Pricing

The proper cost to consider in project evaluation is **opportunity cost**, whether social or private. Where markets operate competitively and efficiently, market prices reflect opportunity costs, and therefore can be used directly in the cost analysis. Outside of perfectly competitive markets, some adjustments are required. Adjustments are especially needed in the developing country context. The adjusted market price, which should be equal to the resource's economic opportunity cost, is called the **shadow price**. Typically, adjustments to market prices to obtain shadow prices are needed when:

distortionary taxes and subsidies cause market prices to deviate from the economic opportunity cost; e.g. subsidised oil production (an input to transport fuel).

monopolies and other market imperfections alter market prices; e.g. oil production has been subject to non-competitive pricing, e.g. by OPEC in the 1970s.

Where resources are **tradable**, taking their international prices corrects for price distortions. Assuming well-functioning markets, these prices are equal to economic costs. This may be applicable to the price of natural gas, for example. If a good is imported or exported, the import or export price can be used. Then these prices should be corrected for taxes and subsidies. Box 3.1 shows a numerical example for a road construction project.

Where the good is **not traded**, the shadow price should be calculated on the basis of the good's production cost, valuing inputs at their economic opportunity cost. Good examples of such goods include most pieces of transport infrastructure. Little and Mirrlees (1974), Ray (1984) and Squire and Van der Tak (1975), have developed methods for making such adjustments, and these methods have been used to estimate shadow prices in a number of countries.

Box 3.1 An Example of Shadow Prices

The following example of a small road construction project in Africa shows how to modify financial costs to reflect true opportunity cost of resources. This project incurs five years of costs in four categories: unskilled labour, skilled labour, capital (domestic), and capital (foreign). The corresponding shadow price coefficients are 0.5, 1.2, 1.4 and 1.6, respectively. The values of 0.5 and 1.2 (for labour) imply that employment benefits for unskilled labour exist, but that skilled labour is paid less than its true opportunity wage rate. The capital values also imply that both domestic and foreign capital are more scarce than their market prices suggest, with foreign capital more scarce than domestic capital.

Table 3.2 below shows how the costs vary once shadow pricing has been substituted for financial costs. Overall cost rises by thirty percent, but the changes in individual costs are as important because they will influence the project design (e.g. substituting unskilled labour for capital where possible).

Table 3.2: An Example of Shadow Price Adjustments to Financial Costs[1]

Year	Unskilled labour		Skilled labour		Domestic capital		Foreign capital		Total	
	F^2	E^3	F^2	E^3	F^2	E^3	F^2	E^3	F^2	E^3
1	100	50	20	24	100	280	100	160	320	514
2	100	50	20	24	60	140	60	96	240	310
3	50	25	10	12	0	0	0	0	60	37
4	50	25	10	12	0	0	0	0	60	37
5	20	10	5	6	0	0	0	0	25	16
Total	**320**	**160**	**65**	**78**	**160**	**420**	**160**	**256**	**705**	**914**

Notes:
[1] All figures are hypothetical and can be assumed to be millions of dollars.
[2] F denotes Financial Cost.
[3] E denotes Economic Cost.

Source: Markandya (1998)

3.2.4 Average, Marginal and Total Costs

Economic analyses frequently use average, marginal and total costs. **Average cost** (AC) is defined as the total cost (TC) divided by the number of units of the item (Q) whose cost is being assessed – that is,

$$AC = TC/Q$$

Average costs are often used to assess air pollution control measure cost-effectiveness (see Section 3.3.2 below). **Marginal cost** (MC) is defined as the cost of producing one more unit of a specific good. In a GHG abatement context, MC is the additional cost of avoiding an additional unit of CO_2 emissions. The marginal cost may also be defined as the rate of change of total cost with respect to the level of pollution abatement, given by

$$MC = \partial TC/\partial Q$$

The case studies in Chapter 5 provide numerical examples of these concepts.

Total cost is the sum of all cost components over time. However, the term is confusing as costs occur at different points in time, and therefore cannot be simply added together. Therefore, a procedure called **discounting** commonly computes the total cost stream's "present value". Furthermore, although a policy's total cost is, in principle, the sum of all cost components through time, it is not always clear whether private and external costs, or only private costs have been included. If both private and some external costs are included, and if future costs have been appropriately discounted, we can refer to the aggregate cost as the programme's **present value total social cost**.

In terms of economic valuation, all three types of cost are relevant. Control measures with given emission reduction targets are evaluated in terms of minimising the **present value of total** (social) **costs**, but decisions about mitigation level to pursue must consider **marginal costs[12]**.

Average costs matter when comparing mitigation options. For example, several options each might reduce GHGs by different quantities. Comparing these options on the basis of the cost per ton of GHG removed essentially compares average costs, **and gives some indication of the cost-effectiveness of the measure**

Box 3.2 Discounting and the Net Present Value

Projects tend to produce a stream of costs and benefits that run into the future. In order to determine how much a project is worth today, one must be able to compare the net benefit received in one time period with the net benefit received in another, thereby linking the stream of net benefits. Present value is the concept used in this comparison, and tells us how much the prospect of future income from a project is worth today after taking into account what is commonly referred to as the **time value of money** (which basically says that a $ today is worth more than a $ tomorrow). The process of calculating present values is called **discounting**.

Discounting allows the estimation of the respective values of costs and benefits in different time periods, by including a measure of time preference. The following formula can be used to estimate the net present value of a project:

$$NPV = \sum_{n=0}^{N} \frac{(b_n - c_n)}{(1+r)^n}$$

Where *b* and *c* are benefits and costs in each period *n* equal to 0,1,…,*N*, and *r* is the chosen discount rate. The determination of *r* is the matter of some debate, particularly in the climate change context due to the long term nature of the benefits of mitigation projects. For a discussion of the discount rate, and its uses, see sections 3.3.3.1 and 3.3.4.1.

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[12] Cost efficiency – i.e. minimising the costs of achieving a given target – requires that marginal abatement costs are equated across all pollution sources. Hence a proper estimation of marginal costs is very important to the development of an efficient pollution control strategy.

3.2.5 Incremental Cost

The term **incremental cost** is used, *inter alia,* by the Global Environmental Facility (GEF), which provides financial support for climate change programmes. They define **incremental cost** as the additional cost a country incurs when undertaking a climate mitigation project, compared with the social cost of the activity the project substitutes. For the purpose of these guidelines, incremental costs are defined as the difference between all costs incurred under policy case 1 or 2, as defined in Chapter 2 and those costs incurred under the **baseline case.**

To estimate GHG mitigation costs we must know what costs are incurred in the absence of the potential mitigation programme, or in other words, under the baseline case. The 'appropriate baseline' however, is not obvious; indeed its determination is difficult. Differences in the baseline case will produce differences in GHG mitigation cost estimates. This was discussed in detail in Chapter 2.

GHG mitigation costs
=
Total cost of the **Mitigation Inclusive Policy case** (1 or 2)
minus
Total cost of **Baseline case**

While a distinction exists between the total and incremental costs of a transport project, both costs are relevant to decision-making. For example, selecting projects to achieve target reductions in particulate pollution (PM_{10}) should seek to minimise **incremental costs**. A project's **total cost**, on the other hand, is relevant to determine its financing, and therefore may be instrumental in deciding which projects will be selected. Consider two projects, A and B, each achieving similar reductions in GHGs, with incremental costs of $20 million and $25 million respectively. The total cost of each project, however, may be reversed, with A costing $30 million and B costing $27 million. Ideally, A should be selected as far as the GEF is concerned, but the government may find it difficult to finance the remaining $5 million and may wish to opt for B.

3.2.6 No regrets options

A 'low carbon' transport project or policy intervention may **reduce** resource use relative to no intervention. For example, introducing efficiency measures that improve the fuel economy of existing motor vehicles, the cost savings from reduced resource use should be subtracted from the other project costs. If these savings outweigh the costs, the net cost of the entire project is negative, and a '**win-win**' or '**no-regrets**' situation exists (where a project or policy intervention may achieve its stated objective at no incremental cost).

Cost savings from project implementation arise because the present resource use is inefficient. Reasons for inefficiency may be unawareness of cost-saving opportunities (i.e. an information problem), the real costs of the project are understated, inertia in

behaviour, or project benefits are external to the decision maker. If "win-win" projects are to be implemented voluntarily by decision makers, they need to address these factors. Of course, this will entail additional costs. These issues are discussed further in Section 3.2.7.2. Examples of '**win-win**' mitigation options are in the Urban Air Pollution Case Study, in which many technical measures generate fuel economy savings in excess of initial investment requirements.

3.2.6.1   Secondary Costs or Benefits

Human welfare must be taken into account when estimating the impacts of any project or policy intervention. Sometimes these impacts relate to reductions in external costs in non-targeted pollutants. s Benefits of this kind are often referred to as **secondary** or **indirect benefits**. They are also referred to as **ancillary** and **collateral benefits**. In this book however, we prefer to use the term **secondary benefits**, as "indirect cost" is a broader concept, including equity and sustainability.

Many transport sector projects have multiple objectives. For example, an urban mass transit system programme seeks to reduce congestion, local air pollutants, and carbon dioxide emissions. In financial and economic analysis, these are referred to as **joint benefit** cases. However, if a project is selected primarily for reducing local pollutants from motor vehicles, and if it has other impacts (e.g. reducing GHG emissions), then it is most convenient to treat any costs or benefits relating to those other impacts as **secondary** project costs or benefits.

For example, if an urban air quality programme introduces technical measures that increase fuel economy, this may not only reduce emissions of local pollutants, but also reduce emissions of carbon dioxide (a secondary benefit), and yield vehicle operators annual fuel cost savings. The net programme cost should be the cost of the technical measures, plus all relevant implementation costs (discussed in section 3.2.7.2), less the secondary benefits, less any resource savings received by the operators.

Projects or interventions also affect employment levels. If a project, such as the construction of a rapid transit system or the installation of CNG refuelling infrastructure, creates a "new" job – i.e. employs a previously unemployed individual - this has a benefit to society equal to the net social costs of the unemployment avoided. These benefits could be deducted from the cost of the project's labour inputs[13]. In other words, the net social costs of avoided unemployment by implementing the project could be a secondary benefit. This can be seen as using a "shadow" wage rate for labour inputs taken from previously unemployed individuals. Measuring employment benefits is considered in more detail in Markandya (1998).

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[13]   NB this does not represent double counting the labour costs of the project; rather, the cost of the labour input is being adjusted to reflect the social costs of unemployment avoided by the project. Of course, if no "new" jobs are created by the project, then no such benefit accrues.

3.2.7 Cost Categories

3.2.7.1 Project Costs

The total social cost of a project includes the 'true' private costs of all resources used by the project over some pre-defined time horizon (usually the useful life of the project), plus any costs imposed on third parties (i.e. the externalities). We must consider the two main categories of private costs, investment expenditures and recurring costs, when estimating the cost of an intervention. **Investment expenditures** are incurred at the project's outset, and do not recur throughout the project's life, hence they are also known as **non-recurring costs**. This cost category typically includes land and property costs, infrastructure expenditures, plant and equipment, and associated installation costs. The Mauritius Alternative Fuel Bus Case Study, for example, required an investment expenditure on the LPG re-fuelling infrastructure of between $530 and $1,260 per vehicle.

Project operation and maintenance usually involves expenses and, as these expenses tend to be incurred annually throughout the life of the project, they are called **recurring costs** (see Box 3.3). Private recurring costs are divided into three broad categories: energy costs, annual labour costs, and material costs. Whether or not recurring costs need consideration depends on the definition of the adopted baseline case and the nature of the intervention.

Box 3.3 Example of Recurring Costs of GHG Limitation Project: Replacing Diesel Buses with OEM LPG Buses in Mauritius

First, suppose the recurring cost of replacing a diesel fuelled bus with an OEM LPG fuelled bus are given by the difference in fuel costs only; i.e. maintenance costs of both types of bus are assumed to be the same.

The fuel economy of a typical diesel bus in Mauritius is 0.284 litres (diesel) per kilometre. Given that the average bus travelled 45,700 km per year, each bus consumed 13,000 litres of diesel fuel. Given that diesel fuel retailed for $0.31 per litre, the annual fuel cost of a diesel bus is $4,000. The useful operating life of an average bus in Mauritius is about 18 years.

Based on field trials, the estimated fuel cost of an OEM LPG-powered bus ranges from 6 to 15 cents per km (mid-point is about 11 cents per km). Hence, the annual fuel cost per OEM LPG-powered bus is about $5,000, assuming constant yearly distance travelled. We estimate the annual fuel cost of a diesel bus to be around $4,000 (see above). The (net) incremental recurring fuel cost is therefore about $1,000 per bus per annum (i.e. $5,000 minus $4000). We assume these net recurring costs accrue annually over the typical OEM LPG-powered bus's useful operating life, i.e. over 18 years.

It is important to remember that private costs, measured by market prices, might need to be corrected in order to more closely approximate to social costs, as outlined in section 3.2.3.

3.2.7.2 *Implementation (or 'Hidden') Costs*

Many aspects of implementation costs are not addressed in conventional cost analyses. Considerable work is required to quantify the institutional and other programme costs, so that the reported figures more accurately represent costs incurred if the programmes are implemented. The implementation of control measures should be considered in the specific context in which the policy is pursued. Sources of **implementation costs** include:

Institutional and human changes.
Information requirements.
Market size and opportunities for technology gain and learning.
Economic incentives needed (grants, subsidies and taxes)[14].

Costs arising from the above can be divided into **administration costs** and **barrier removal costs**.

Administration costs are activity costs directly related and limited to short-term project implementation, and include planning, training, administration, and monitoring costs. Introducing LPG-powered buses in Mauritius, for example, would require a phase-out of currently operational buses, together with the extra training of the island's garage personnel, needed to ensure proper maintenance of the new vehicles.

Barrier removal costs are costs of activities aimed at correcting market failures directly or at reducing transaction costs in the public and/or private sector. These activities should support project implementation. Examples of barrier removal costs include costs of improving institutional capacity, reducing risk and uncertainty, facilitating market transactions, and enforcing regulatory policies. Introducing a carbon tax, for example, would require some increase in institutional capacity in order to ensure tax collection.

Typically, implementation costs will be dynamic (they will be incurred over time), and the associated policy's effectiveness will likewise change over time. Implementation costs may also be closely linked to general economic policies, for example those related to financial markets, general tax policies, and international economic relations. Implementation cost studies therefore should include an assessment of economic policies and potential synergies and conflicts relating to climate change policies. The dynamic nature of implementation costs is highlighted in Fernando and Munasinghe (1999), who argue that a dynamic cost curve provides more protection against uncertainty.

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[14] Taxes and subsidies are not themselves elements of social cost. They are, however, relevant to social cost estimation in so far as they have an impact on the efficiency of resource use. It is this change in efficiency that is relevant to the social cost estimation. Moreover, taxes and subsidies have a significant impact on implementation rates (e.g. the penetration of a specific technology), which in turn, affects the cost/benefit profile over time.

In summary, the scope of the cost categories considered in these guidelines is wide. **All** changes in resource use resulting from potential projects or policy interventions should be valued. These values form the basis of project or policy costs. Project costs include the resources such as land, labour, energy and physical capital, which may comprise a **recurring** and a **non-recurring** element, or in some cases, just a **non-recurring** element. They may also include changes in less obvious societal resources, such as clean air and water (i.e. **external costs**). Finally, they may include 'hidden' resources required to achieve changes in policies – costs of barrier removal and implementation.

3.3 Decision-making framework

3.3.1 Introduction

Once all the resource inputs to a project or policy intervention are valued and the outputs quantified, if not also valued, the next step is to assess the (economic) desirability of the project or intervention. As noted in section 2.4, **cost-effectiveness analysis** (CEA) is the main analytical method used to assess the economic desirability of interventions in the climate change mitigation context. For example, when dealing with the vehicle emission-fuel quality-air quality management nexus, the World Bank advocates the "*use of cost-effectiveness analysis as the primary criterion for selecting optimal strategies across various sources and sectors*" (World Bank, 1999). The main alternatives to this method are **cost-benefit analysis** (CBA) and **multi-attribute** (or **criteria**) **analysis**, the latter of which is not discussed here. For further discussion of decision-making methods in general see Toth (1999)

3.3.2 Cost-Effectiveness Analysis

Cost-effectiveness analysis (CEA) seeks to find:

- the least-cost (most efficient) way to achieve a goal, e.g. a given reduction in emissions of a targeted pollutant; or

- the project or policy package yielding the greatest benefit (e.g. a reduction in exposure to certain toxic VOCs), subject to a compliance cost constraint.

The mechanics of pursuing both agenda are the same – the difference is a matter of emphasis – as are the cost definitions and the way in which they are quantified.

In contrast to CBA, CEA does not require that the project or intervention's output (benefit) be expressed in monetary terms. Only project inputs (costs) are monetised as it is sufficient to express the benefits in physical units, e.g. in tonnes of CO_2 eq. abated per year. This is advantageous when output valuation is controversial, uncertain or both. The underlying principle of CEA, as illustrated by the first bullet point above, is to determine a project's effectiveness (in terms of the total required

expenditure) in producing a specific benefit level. At the policy level, CEA is used primarily to identify the 'least-cost' strategy for meeting a set objective[15]. In the context of GHG limitation, for example, CEA may be used to achieve a given reduction target at 'least-cost'.

CEA is not restricted to generalised (private) costs, as defined above. It is often desirable in the context of climate change mitigation project analysis to work with **social costs**. Hence, in addition to resource inputs and time costs, the cost component may also include avoided costs (e.g. savings in fuel costs), secondary benefits (e.g. the social costs of unemployment avoided, collateral air emission savings) and implementation costs. In this respect, only the monetary benefits directly associated with the physical output (or policy objective) are excluded. For example, the (purely financial) cost-effectiveness of replacing diesel buses with OEM LGP equivalents in reducing GHG emissions has been estimated at $US 1,800 per tonne of CO_2 eq. abated (Markandya and Boyd, 1999). However, when the cost component is expanded to include the social costs of avoided unemployment and secondary (collateral) emission savings – i.e. as the cost analysis moves towards the concept of full social cost - the bus replacement programme's cost-effectiveness becomes $US 600 per tonne of abated CO_2 eq.

3.3.2.1   *Measuring Cost-Effectiveness*

A project or policy intervention's cost-effectiveness in delivering a given output, for example GHG emission reductions, may be calculated in two ways:

1. Cost-effectiveness ($/unit reduction) = present value of project's 'net' incremental cost stream ÷ present value of the stream of annual emission savings associated with the project.

2. Cost-effectiveness ($/unit reduction) = the total net annual incremental cost of the project ÷ average annual emission savings associated with the project.

The first calculation is based on net present value, the second based on **levelised cost**. In most situations, both approaches produce the same cost-effectiveness measure. However, the net present value approach offers greater flexibility in terms of manipulating key input parameters, such as accounting for variations in fuel prices or emission factors over time.

There are also two methods for calculating a project's **total annual cost**. Estimates of a project's total annual cost are a necessary input to cost-effectiveness calculations. Total annual costs are:

1. Total annual cost = annual capital cost (yearly depreciation charge plus average interest cost per year) + net annual operating and maintenance costs.

2. Total annual cost = the present value of the total cost stream (investment expenditure plus net operating and maintenance costs) x capital recovery factor.

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[15]   CEA may equally be used to maximise physical benefit subject to a cost constraint (second bullet point above).

In most situations, both approaches produce the same total annual cost, but the second approach offers greater flexibility, and it does not depend on adopted accounting conventions. Both methods may be used in the numerator of the levelised cost approach to estimate a project's cost-effectiveness.

Annex II shows how each of the above methods for estimating total annual costs is used in a generic project. Using these estimates to calculate the project's cost-effectiveness in abating GHG emissions is also illustrated.

3.3.2.2   Abatement Cost Curves[16]

A useful way to present analytical results from a cost-effectiveness analysis of GHG limitation scenarios is to use (marginal) abatement cost curves. These curves express "*the relationship between the minimum cost to society of reducing an additional ton of GHG and the corresponding level of emission reduction*" (Halsnaes et al, 1998). Costs and emission reductions are, of course, defined relative to the Baseline Case. Typically, potential emission reductions (e.g. tons of CO_2 equivalent) are presented on the horizontal axis, and the cost of abating one ton of emission (e.g. US $ per ton CO_2 equivalent) is on the vertical axis. Constructing abatement costs curves starts by determining the cost-effectiveness of limitation measures under consideration (as illustrated above). Limitation measures then are ranked sequentially according to increasing unit costs. Abatement cost curves therefore rise to the right, reflecting the fact that increased levels of abatement are achieved at higher unit costs.

Cost curves may take various forms (e.g. single cost curves or compound cost curves), may be assessed relative to different baselines (e.g. base year emissions or future baseline scenario emissions), and may be constructed in one of several ways (e.g. the partial approach, the retrospective systems approach, or the integrated systems approach).

Single cost curves consider only one pollutant, showing, for example, only SO_2 emission reduction potential and associated costs. **Compound cost curves**, as the term implies, consider more than one pollutant and hence represent more comprehensive environmental issues. Compound cost curves are more likely to be used in transport scenarios owing to the fact that vehicles produce multiple pollutants. The cost curve constructed in the Urban Air Pollution Case Study (see Chapter 5) is a compound cost curve in which reductions in PM, HC and CO are all shown on the same curve – expressed in terms of PM equivalents.

In order to assess the cost effectiveness of projects and policies in regard to air emissions, cost curves can be constructed in the following ways:

Partial Solutions: Each mitigation option is taken separately. Cost-effective measures of each option are computed relative to a baseline. Mitigation options are

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[16] Other terms frequently used include avoidance cost curves, emission reduction marginal cost curves, incremental cost of abatement curves, abatement supply curves, elimination cost curves or prevention cost curves.

ordered by unit costs of GHG reduction, and curves are constructed using the (unit) costs of individual options. This approach does not take account of interactions between measures, and so environmental performance of the listed measures may not be strictly additive (Xie, *et al*, 1998). Such interactions must be addressed before constructing an accurate abatement cost curve, from which an effective control programme can be designed. In short, curves based on this approach may be seen as a starting point for mitigation programme development; they show the broad relationship between emission reduction potential and the cost of those reductions.

Retrospective Systems Approach: This approach extends the partial solutions approach, by explicitly considering the interdependence of mitigation measures and, if appropriate, previous abatement projects. For example, the implementation of one measure may alter the cost-effectiveness of another measure by altering the emission baseline when measures are used in sequence or in parallel. In contrast to the partial solutions approach, this approach, through an iterative technique, re-ranks mitigation options and adjusts for interactions between measures that are not mutually exclusive. Abatement curves based on this approach provide sufficient detail to estimate the specific costs of mitigation scenarios.

Integrated Systems Approach: This approach uses a full transport system model to derive cost curves. With the integrated systems approach, a detailed modelling exercise takes into account all relevant interactions in the sector- resulting in a smooth marginal abatement cost curve, as opposed to the standard "step-wise" curves. Consequently, any point on the cost curve represents a least-cost solution for the transport system. Clearly, more accurate mitigation strategies are developed under this approach.

For a more detailed discussion of these variations see (Halsnæs et al, 1998), Risoe National Laboratory (1994) or FSO (1996).

3.3.3   *Cost-Benefit Analysis*

An alternative decision-support tool is **cost-benefit analysis (CBA)**, which is designed to show whether a project's total benefits exceed its total costs. CBA compares project cost and benefit streams (i.e. the costs and benefits occurring at different points in time)[17], and applies a decision rule (or formal selection criteria). This requires that project benefits, to the extent possible, be expressed in monetary terms. Applying formal selection criteria to cost and benefit streams reveals whether a project is worth implementing.

The Urban Air Pollution Case Study in Chapter 5.2 presents a simplified CBA of a "local" versus "global" air pollution abatement programme. The case study places a monetary value on the CO_2 eq. emission reductions, thereby converting the cost-effectiveness results into quantified net benefit, the cornerstone of CBA. However, we should note the reason why cost-effectiveness analysis was used in the first place - it removes the need to use the uncertain damage cost estimates for carbon emissions. As mentioned above, a relative advantage of CEA is that the direct policy outputs do

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[17]   Issues associated with the time dimension are discussed below.

not need to be valued. This is fine where a prior decision has been made to reduce CO_2 eq. emissions to a desired level, and the issue is solely to do so at least-cost. However CEA cannot determine the appropriate emission reductions level, nor can it compare different air quality standards. Moreover, CEA says little about the total budget allocated to the policy objective. Most projects involve one or other of these issues.

3.3.3.1   *Formal Selection Criteria in CBA*

Three discounted project selection criteria are widely used in investment (CBA) decision-making: **net present value** criterion, **benefit-cost ratio,** and **internal rate of return**. They are referred to as "discounted" criteria because they compare discounted cost and benefit streams. This "time dimension" of project evaluation is discussed below in Section 3.3.4 below. In most cases, these criteria indicate whether a donor financed project meets the two conditions outlined in Chapter 1, which defines when a project is acceptable on economic grounds as being where:

♦ The project's expected net present value must not be negative; and

♦ The project's expected net present value must be greater than or equal to the expected net present value of mutually acceptable project alternatives.

The principal selection criterion is the **net present value** (NPV) method, which is given by the present value of the estimated benefits net of costs. For an **independent project**, i.e. a project that is not in any way a substitute for another project, the decision rule is to "accept the project if its NPV is greater than zero". A positive NPV indicates that a project's total benefits exceed its total costs. By undertaking a project with a positive NPV, social welfare will increase by the magnitude of the estimated NPV. If, in contrast, the NPV of a project is negative, the funds that would otherwise have been used for this project should be allocated elsewhere.

The **benefit-cost ratio** (B/C) is simply the ratio of the project's discounted aggregate net benefits (i.e. benefits minus costs) to the discounted investment costs. A project should be accepted "if its B/C ratio is greater than 1", meaning its NPV is positive.

The **internal rate of return** (IRR) is used by most donor agencies, and is that rate of discount equating discounted net benefits to discounted investment costs. A project is acceptable if its IRR is greater than the selected rate of discount (the NPV of the project will be positive).

A numerical example of these three project selection criteria in relation to a road-building scheme is illustrated below in Box 3.4.

Box 3.4 Project selection criteria in CBA

The net present value (NPV) of a project is given by

$$NPV = \sum_{n=0}^{N} \frac{(b_n - c_n)}{(1+r)^n}$$

Where b and c are benefits and costs in each period n equal to $0,1,\ldots,N$, and r is the chosen discount rate. For example, consider the road-building project shown in the table below. The initial expenditure on infrastructure is $60 million, including materials, equipment, labour, etc. Recurring maintenance costs are $5 million per year. The benefits are of three types: time saving, employment gains and health effects (resulting from, say, lower PM emissions).

Road Construction Scheme

	2000	2001	2002	2003	2004	2005
Costs						
Investment cost	60	0	0	0	0	0
Maintenance cost	5	5	5	5	5	5
Total cost	65	5	5	5	5	5
Benefits						
Time savings	6	6	6	6	6	6
Health Benefits	12	12	12	12	12	12
Employment Benefits	15	3	3	3	3	3
Total benefits	33	21	21	21	21	21
Net Benefits	-32	16	16	16	16	16
NPV (10% discount rate)	26.05					
NPV (0% discount rate)	48.00					

The road's net present value is given by the sum of the discounted net benefit stream. In this simple example the NPV is positive, which means the project is economically desirable. As the table shows however, the applied discount rate may have an important impact on the net present value and hence the viability of the project. (Issues relating to discounting are discussed in Section 3.3.4.1.)

The benefit-cost ratio (B/C) is generally defined as:

$$B/C = \frac{\displaystyle\sum_{n=0}^{N} \frac{(b_n)}{(1+r)^n}}{\displaystyle\sum_{n=0}^{N} \frac{c_n}{(1+r)^n}}$$

Using the same figures in the above example, the *B/C* ratio is 0.43 for the case where $r = 10\%$.

The internal rate of return (*IRR*) is the discount rate satisfying the following relationship:

$$\sum_{n=0}^{N} \frac{I_n}{(1+r)^n} = \sum_{n=0}^{N} \frac{(b_n - c_n)}{(1+r)^n}.$$

where I_n is the investment cost in year n. In this example the IRR is 41%.

3.3.3.2   Single Period Input Constraint

If unlimited resources (inputs) are available, a public agency should adopt every project with a positive net present value. This would secure higher net benefits than from using those inputs in any other way[18]. Public agencies however, usually face 'input constraints'. The most common constraint is capital funds, so a public agency must rank policies in terms of desirability, working down the list until available investment funds are exhausted.

Limited capital funds require project proposal ranking. If the objective is to maximise the total present value over the group of possible project options, this implies that it should seek to maximise the net benefit per unit of constrained input (in this case, investment costs). This can best be achieved by using a measure known as the **net benefit investment ratio** (NBIR).

The **NBIR** is the ratio of the present value of a project's benefits minus its recurring costs to the present value of its investment cost. This is the correct assessment criterion to use when there is a single period budget constraint because it indicates which of the alternative viable projects will earn the greatest net receipts per unit of investment. A project's NPV, on the other hand, only shows the difference between its discounted benefits and discounted costs over the project's lifetime. The policy with the highest NPV is not necessarily the one with the highest net benefit investment ratio.

3.3.4   The Time Dimension

Project costs are incurred at various points in time. At the simplest level, investment in a project is incurred in the first few years of the life of the project and thereafter the project entails some operating (recurring) costs. Evaluating such projects includes accounting for all such costs, but we cannot treat a dollar spent/received today and a dollar spent/received in the future, as equivalent. In some cases, a project incurs costs far into the future. Two issues arise from the time dimension: discounting and future costs forecasting.

3.3.4.1   Discounting
The **present value** cost of a project is the sum of all the costs of a project over all periods, with future costs discounted to a given base year (typically, $t = 0$). For a project that has costs C_t in period t the present value cost of the project is:

$$\sum_{t=0}^{T}\left[C_t \times \frac{1}{(1+r)^t}\right]$$

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[18]   Of course, this assumes, albeit unrealistically, that the public agency has only one objective, i.e. to maximise net social benefits.

where the useful life of the project is T years, and the annual **discount rate** is r. The second term in the brackets is the **discount factor**. If all costs are expressed in **current prices**, then the discount rate chosen is called the **nominal** discount rate[19]. If the costs are in **constant** (**real**) prices, the discount rate chosen is called the **real** discount rate[20]. Some form of discounting is required to determine a policy's cost-effectiveness (illustrated in Annex III), or to compute one of the decision criteria used in CBA (as shown in above).

The discount rate debate is a long-standing one, and has produced two approaches to discounting; an ethical approach based on what discount rates **should** be applied, and a **descriptive** approach based on what discount rates people (savers as well as investors) actually apply in their day-to-day decisions (IPCC 1996b, 2001b). The former leads to relatively low rates of discount (around 3% in real terms) and the latter to relatively higher rates (above 10% and, in some cases much higher rates). The higher the discount rate applied to the cost streams, the lower the present value. Weitzman (1998) found that professional economists suggest decreasing (from 4% to 0%) discount rate, as the perspective shifts from the immediate (up to 5 years hence) to the far distant future (beyond 300 years). Based on his survey, Weitzman suggests that the appropriate discount rate for long-lived projects tends towards slightly less than 2%. Discount rates in the region of 4-6% are applicable for the opportunity cost of capital in the developed world, though in the developing world the rate could be 10-12%.

The choice of discount rate thus has both economic and political significance. As a result, present values are usually calculated for more than one rate and provide policy-makers guidance on how sensitive the results are to the choice of discount rate[21]. Lower rates are typically based on ethical considerations. A higher rate is usually based on the opportunity cost of capital, or what the same capital, with similar risk, could earn on other projects.

3.3.4.2   Cost Forecasting

Another issue related to the time dimension is the need to forecast future costs, clarifying assumptions underlying forecasts. These assumptions include but are not limited to:

- future population growth,
- urbanisation rates,

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[19]   Current (or nominal) price variables refer to values at the prices ruling when the variable was measured. Such prices have not been adjusted for the effects of inflation. In contrast, real or constant price variables adjust nominal variables for changes in the general level of prices – i.e. they are inflation-adjusted prices. This distinction is illustrated below.

[20]   The real rate of discount is calculated by dividing the market rate by the rate of inflation. Thus, if a market has a discount rate of 12% and inflation is 8% the real rate is (1.12/1.08=1.037) or 3.7%.

[21]   It is also useful to display graphically the time path of undiscounted costs as discounting can obscure important information.

- income growth,
- land use,
- fuel economy,
- motor vehicle and emission control technology,
- emissions rates,
- prices (issues associated with prices are examined below)

It is also important to know how underlying assumptions are used to generate the forecasts. Changes in some of the variables listed above may affect the values of other variables. For example, changing motor vehicle technology will affect fuel economy, which will affect operating costs, which will affect travel demand and which, in turn, will affect emission rates.

3.3.4.3 *Price Changes over Time*

The general price level and the relative prices of goods and services change with time. This means that individual component costs and the overall total cost of a project will also change over time, which presents two potential problems for costing studies.

The price of individual cost components (specifically energy, materials, and labour) may vary over the useful life of a project, either because of general price **inflation** or because of a change in their **relative prices**. A project's cost should be valued in **real** or **constant** prices, which are usually the prices prevailing at the **base year** of the study. Real prices are simpler to use, it is easier to make inter-temporal comparisons using constant prices, and the results are not influenced by the underlying rate of inflation.

Using real cost data presumes that the price of all cost components changes at the same rate as the **general price level**, so that prices remain constant relative to each other. If the **relative price** of a cost component is expected to change over the life of the project, however, then this change in its real value should be accommodated. Otherwise, it is an implicit assumption that all cost data remain constant in real terms.

When comparing costs between projects (e.g. technical control measures) it is important to ensure that all unprocessed cost data are expressed on an equivalent price basis, i.e. in the prices of a common year, whether it is in **nominal** or **real** terms[22]. Moreover, if the cost data is an input into an economic analysis, the chosen 'common' year should be the analysis base year. A general procedure for expressing the unprocessed cost data in the prices of a selected year is shown in Box 3.6, along with a numerical example, expressed in terms of the base year of a study, though it could just as easily refer to any year of interest.

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[22] For example, the capital equipment costs of one pollution control system may be valued at **current prices** in 1991, whereas the capital equipment costs of another system may be valued at **current prices** in 1995. Direct comparison of the two data sets would be misleading. Also, cost data for some projects may only be available for years other than the 'base year' of the study for which the data is an input. For example, a reference may quote the incremental cost of catalyst as $500 per vehicle in 1992, yet the base year of the study for which the data is required might be 1995. Assuming prices have changed over the intervening period, if the quoted cost is used directly in the study, the results will be underestimated. Equally, if the base year is 1990 and the quoted cost is used directly, the results will be overestimated.

Box 3.6 Example: Expressing the Original Cost Data on an Equivalent Price Basis

Consider a transport project with annual energy savings of $5,620 recorded at *current prices* in 1991, i.e. it saves 1 GWh of petroleum product per year at a price of 0.562 cents per kWh. Suppose that it is necessary to express this control system's cost data in 1995 prices because 1995 is the study's base year. The required adjustment is shown below. The annual energy savings at *current prices* in 1995 are $7,310 (i.e. 1 GWh x 0.731 c/kWh); in *real* terms, the annual energy savings are $6,500 (i.e. 1 GWh x 0.650 c/kWh).

Step 1:

price adjuster: 1.301
equals
current price index energy consumption in transport sector (1995): 114.2
divided by
current price index energy consumption in transport sector (1991): 87.8

Step 2:

'*nominal*' price of petroleum product in 1995 prices: 0.731 c/kWh
equals
'*nominal*' price of petroleum product in 1991 prices: 0.562 c/kWh
multiplied by
price adjuster: 1.301

Recall that: '*Nominal*' price series in a given year divided by the *price deflator* in that year (x 100) equals the '*real*' price series. The future *real* price in a given year is equal to the future *nominal* price divided by one plus the prevailing inflation rate over the study period. Therefore, using the seasonally adjusted GDP deflator at market prices to measure *inflation* between 1991 and 1995:

'*real*' price of petroleum product in 1995: 0.650 c/kWh
equals
'*nominal*' price of petroleum product in 1995: 0.731 c/kWh
divided by
change in GDP deflator from 1991 to 1995: (119.8 ÷ 106.5).

The last step above is equal to:

one plus the inflation rate between 1991 and 1995: 1.125
equals
seasonally adjusted GDP deflator at market prices (1995): 119.8
divided by
seasonally adjusted GDP deflator at market prices (1991): 106.5.

Transport sector projects often require foreign currency, which is a good, just like cars or fuel, and like any other good, foreign currency has a price – known as its **exchange rate**. Like other prices, exchange rates vary over time. For example, if the price of the domestic currency declines (depreciates) over time relative to a foreign currency, more units of the domestic currency are required to purchase one unit of the foreign

currency[23]. Conversely, less foreign currency is required to purchase a unit of the depreciated domestic currency.

The impact of currency depreciation/appreciation relative to another currency is similar to the currency depreciating/appreciating relative to the price of other goods. For example, the dollar's depreciation relative to foreign currencies means that there has been inflation in the dollar relative to, say, the Rupee. In other words, more dollars are required to purchase one Rupee. Failure to take into account exchange rate fluctuations over the life of a project, including from the time the economic analysis is conducted until the project is actually initiated, may affect the project's net benefit flows and thereby its economic desirability. Consequently, accurate forecasts of expected exchange rates are important for management of foreign exchange risks.

3.4 Summary

This chapter has presented the definitions of various cost concepts used in climate change mitigation project analysis. Concepts such as private cost, social cost, external cost and opportunity cost allow analysts to elucidate the problem of costing projects which address externalities. Of particular importance to climate mitigation is the concept of incremental cost, for which GEF funding may be available (see Chapter 9).

No-regrets options may exist where a project or policy achieves its stated objective with no incremental cost. Such cases may be particularly true when secondary or ancillary benefits are taken into consideration. However, implementation or hidden costs may exist that would hinder projects. Such implementation costs include administration costs and barrier removal costs, and these need to be taken into account in project analysis of mitigation-related projects in the transport sector.

This chapter presents two possible decision making frameworks: cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA). In contrast to CBA, CEA does not require that the project or intervention's output be expressed in monetary terms. As such where the benefits of a given project are uncertain or unquantified, as is the case with mitigation policies, CEA may be used to achieve a given reduction at least cost. Abatement cost curves can be constructed using either partial solutions, the retrospective systems approach, or the integrated systems approach in order to aid policy analysis. Within CBA, different measures of a policy or project's impact exist: the net present value, the benefit-cost ratio and the internal rate of return. The net benefit investment ratio facilitates project proposal ranking in the case of limited capital funds.

Discounting of future costs and benefits is an important issue in the context of the climate mitigation debate. The choice of discount rate has both economic and political significance, with the consequence being that sensitivity analysis using different discount rate is often conducted to better inform policy makers. Another important

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[23] Three relationships can lead to a decline in the value of domestic currency: (1) having a higher rate of inflation; (2) having the domestic real interest rate fall relative to that of the foreign country; and (3) having higher growth in domestic income.

issue related to the time dimension is that of the need to forecast future costs and the consideration of price changes over time.

The next chapter addresses a number of new conceptual and practical issues involved in the implementation of GHG reduction inclusive policies in the transport sector.

4. Policy perspectives on GHG reduction objectives in the transportation sector

4.1 Introduction

This chapter addresses a number of new conceptual and practical issues involved in the implementation of GHG reduction inclusive policies in the transport sector. Transport is the GHG-emitting sector that has experienced the largest growth in activity in the last decade and this trend probably will continue (Schipper and Marie-Lilliu, 1999). This strong growth in activity is a consequence of generally high transport demand/GDP elasticity and a relatively limited supply of low-cost, lower GHG emission options than conventional fossil fuel based technologies currently in use. Also prevalent in the transport sector are conflicting stakeholder groups, synergies and tradeoffs between global objectives and local environment and development objectives, all of which, constitute a very complex control problem.

The chapter discusses the potential for and costs of GHG reduction inclusive policies with regard to synergies and tradeoffs with urban air pollution control programmes. Consequences of conflicting policy priorities for global and local environmental externalities are reviewed in Chapter 6 where case studies for Mexico, Santiago and a stylised New Delhi case study are presented.

The discussion here represents a preliminary attempt to establish cost-effective GHG reduction inclusive policies in the transportation sector. This reflects the fact that there have been very few practical experiences to date of GHG emission reduction policies in the transportation sector and limited associated cost effectiveness studies. This contrasts with the extensive information that exists for other major GHG emitting sectors such as energy and forestry. The approach suggested here is a first step in the development of a framework that, through its application in more case studies, may lead to deeper insights into the potential for cost-effective GHG emission reduction potentials in the transportation, and other, sectors.

4.2 GHG Emission Reduction Policies in the Transportation Sector

Developing countries with low current transportation demand are expected to experience large increases in GHG emissions in the future as transportation activity rises. Improving transportation facilities in such countries is a key component of economic development strategy, and international donors are leading partners in providing finance for transportation programmes, particularly those related to road transport systems. Such investment programmes will generally lead to increased total transportation services and so, also, to increased GHG emissions, depending on the efficiency and GHG emissions of the vehicles using the new transport infrastructure. This issue is explored in more detail in the following section.

There is, however, potential for the implementation of GHG-related policies in the transportation sector, in conjunction with urban air pollution control programmes. Currently, for example, the World Bank is involved in promoting air pollution control programmes in large cities in Latin America, Eastern and Central Europe, Africa, and Asia. Cities are considering a range of air pollution control options such as demand management, changes in modal structure, use of low-GHG fuels, and vehicle technologies, and they are likely to lead to synergies and tradeoffs with global priorities.

In addition, transportation policies are closely linked to general development programmes and as a consequence have an effect on other social objectives such as income distribution, social exclusion (via access to transport) etc. Integrated transportation and GHG mitigation policies must balance all these different interests such that the implementing agency as well as local governments and other stakeholders accept the programme activity as a fair representation of their policy objectives.

4.3 Implementation Issues in GHG Emission Reduction Transport Policy

Implementing GHG emission-reducing transport requires policymakers to address assumptions underlying expected future emission growth. As noted above, they must also address the complexities in policy design resulting from the close inter-relationships between local and global externalities.

4.3.1 Future Growth Trends

Many transportation programmes will generate increased transportation activity due to better infrastructure, fuel substitutions or efficiency improvements, or other user cost savings that lead to increased demand. These strong transportation sector growth tendencies must be addressed in GHG reduction policies to ensure that they produce real GHG emission reductions.

The case study of a highway project in China in Chapter 5 provides an example of a transportation activity that results in increased GHG emissions. The highway project estimated a total increase in the traffic volume from about 300 thousand vehicles per day to about 430 thousand vehicles per day in 2010, resulting in a GHG emission increase of 0.34 million tonnes carbon. A GHG reduction strategy applied to this project would be able to generate a decrease in the GHG emission intensity of the traffic through a project component that substitutes efficient diesel trucks for gasoline trucks. The argument for integrating this specific programme component into the highway project is that these large programme activities of international donors provide an opportunity for policymakers to address other policy objectives as part of the general planning activities initiated for the transportation sector in China.

A transportation reform programme, which is the baseline case for the GHG reduction assessment, suggests larger GHG emissions (in absolute terms) than a Business As Usual case with no transportation reform. The GHG mitigation component of a transportation programme can aim to reduce (but not necessarily to offset totally) the GHG emissions due to activity increase. The appropriate way to assess GHG emission

reductions from a mitigation inclusive policy is to compare GHG emissions from the GHG reduction inclusive policy to those from the reform programme.

GHG reduction inclusive policies also may lead to increased GHG emissions in absolute terms, particularly if such policies lead to decreased user costs to vehicle owners, which may increase demand and GHG emissions. The ensuing emission "leakage" can be avoided by introducing carbon taxes or other market instruments. Several issues related to carbon taxes in developing countries are discussed in Chapter 8[24].

In some cases a donor may wish to introduce a GHG reduction inclusive programme additional to any existing transportation reform programme in place. The only available reference point for assessing the GHG emission implications of such a policy would be a Business As Usual baseline case. Using such a case, however, means that all changes in transport activity (and in GHG emissions), generated will be attributed to that policy, and it will be difficult to verify the impact of any GHG emission reductions. Therefore, we suggest that the actual GHG emission changes of such a policy are measured against a defined baseline case that includes assumptions about future transport activity increases. Such a baseline case can be defined in one of the following three ways:

1. A specific "benchmark" technology can be used for each sub-component of the GHG reduction inclusive policy, with GHG emission reductions calculated with reference to each benchmark. The activity increase caused by the GHG reduction inclusive policy should also be calculated with reference to the benchmark option.

2. The GHG emission reduction generated by the GHG reduction inclusive policy is calculated as the difference between the GHG emission per unit of transport in the policy and baseline cases.

3. A 'shadow' transportation programme is defined and then used as a reference point for the performance of the policy.

The first of these three methods is the most straightforward. A benchmark is a standard against which are measured GHG emission reductions over the whole project period, according to the rules specified by funding mechanisms like the GEF or the Clean Development Mechanism of the Kyoto Protocol (see Chapter 9). The second method is more difficult to use but its advantage compared to the benchmark approach is that it reflects the real state of the transport sector. The third method maybe the most appropriate, but is demanding in its practical application.

4.3.2   Local and Global Externalities

GHG reduction inclusive policies have multiple policy objectives, including those related to general economic development, social issues and environmental policies. Therefore, GHG reduction inclusive policy objectives must be selected carefully, accounting for potential tradeoffs and synergies between the different impact areas.

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[24]   These issues are also discussed in depth in Eskeland and Xie (1998).

Integrating air pollution control and GHG emission reduction policies depends on policy objective specification and the application of these specifications to policy options and instruments. Three different types of policy approaches are discussed below:

1. The policy is initiated as a local air pollution control programme, with technical options selected on this basis. Subsequently, GHG emission reduction objectives are integrated into the local air pollution control programme.

2. GHG emission reduction takes priority, with impacts on local air pollution and other environmental targets considered as side-benefits.

3. Local air pollution control and GHG emission reductions are prioritised equally, using options and instruments designed to pursue both these objectives simultaneously.

Results of each of these approaches, measured in costs per reduced unit of local pollution, costs per unit of GHG emission reduction and financial and social costs to donor organisations and the local government vary further depending on values assigned to the following assumptions:

- Degree of implementation of no-regret options related to urban air quality or efficiency improvements in transportation systems.
- Options and instruments considered in the baseline and policy case.
- Cost, emissions and efficiency of technical options and regulation efforts.
- Finance rules assumed for various policy components.

The type of costs implied by these assumptions are reviewed in relation to energy sector studies in the IPCC Third Assessment Report, Chapters 7, 8 and 9 (IPCC, 2001b), and are also discussed in relation to the development of financial principles for Climate Change activities by GEF (see Chapter 9).

By way of illustration, the study by Eskeland and Xie, (1998), of urban air pollution control programmes for Mexico City and Santiago, is structured according to policy approach (1) above, where the GHG emission reduction objective has been latterly integrated into studies originally structured around local air pollution control.

The study, using cost-effectiveness analysis, produces results that are presented in cost curves and that illustrate the marginal cost of air pollution control policy options versus reductions in locally weighted pollutants and associated GHG emission reduction. Figure 4.1 shows the pollution abatement curve for Santiago, including three control options: emission standards for diesel buses (Bus '91 stds), standards for diesel trucks (Truck '91), and standards for light-duty gasoline vehicles (LDGV '93). All of these options are attractive compared with the local benefit of pollution reduction, which was estimated to be $18,200 per ton of PM_{10}. The upper dashed line includes local benefits and costs while the lower dashed line reflects a subsidy for associated GHG emission reductions of $20 per tC. The impact of this subsidy for global benefits seems to be very small. The only option that had significant impacts

on GHG emissions was the LDGV measure and the $20 per tC value applied in this study was not large enough to generate a re-ranking of the considered options.
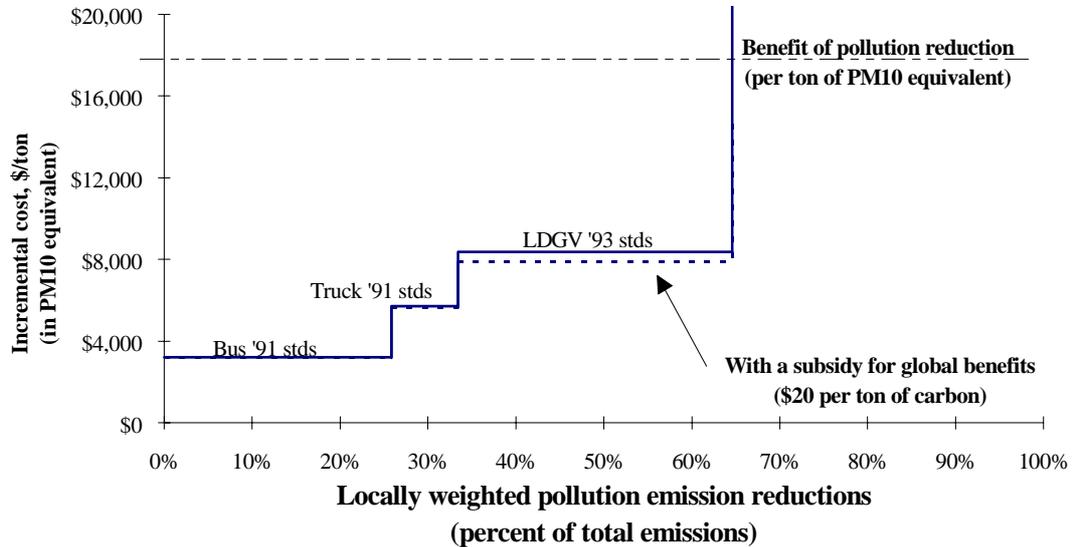
Figure 4.1 The Pollution Abatement Curve in Santiago Chile (accounting for global benefits)

Eskeland and Xie also assessed the implications of combining a local air pollution control option and carbon taxes to reduce GHG emissions. They found that the principal effect of the carbon tax would be to turn users away from GHG-intensive activities in the transport sector as a result of general efficiency increases, substitution of low GHG emission intensity fuels, and depressed demand. The Santiago programme GHG emission reductions, which include only the aforementioned technical air pollution control options, as well as another programme combining the technical options and carbon taxes are illustrated in Figure 4.2.
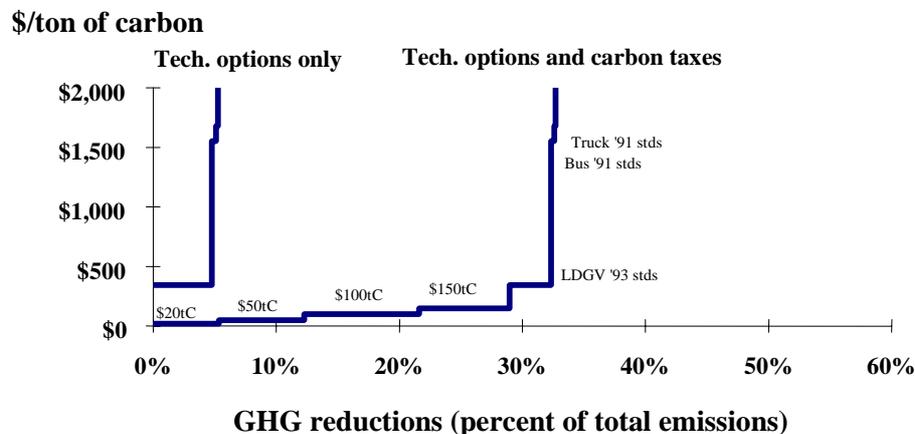
Figure 4.2 GHG Reduction in Santiago, Chile (technical options and fuel taxes)

When viewed from the narrow perspective of greenhouse gas reductions, Figure 4.2 reveals that all three technical options are costly and offer only very small emission reductions. The illustrated levels of carbon taxes offer GHG reductions much more cost-effectively. We conclude that the combined policy efforts may be attractive to the local government if international financing is supplied to compensate for the welfare loss imposed by the carbon tax.

Another study by Dessus and O'Connor (1999) uses policy approach (2), assessing, like Eskeland and Xie, the joint benefits of an air pollution control programme in Santiago. The study is based on pollution damage estimates from the World Bank urban air pollution control programme for Chile, but considers GHG emission reductions as the primary policy objective and local air pollution control as a secondary objective.

In the Dessus and O'Connor study, a Computable General Equilibrium (CGE) model is used to compute the welfare impact of ancillary benefits to GHG abatement on local air quality and health damages. The study assumes introduction of a carbon tax, and assesses gross welfare costs of this tax and the net social benefits expected to emerge in the form of cleaner air and improved health conditions. Local air pollution control policies are not assumed to have been implemented and these policies are therefore not part of the baseline case.

This study concludes that for CO_2 reductions amounting to between ten and twelve percent of baseline emissions over the next decade, benefits to Chile are likely to exceed the costs. This result can be explained by the fact that the model accounts for changes in patterns and levels of fuel consumption following the imposition of a carbon tax, and that result in a net reduction of other air pollutants and their associated health damages. However, it should be noted that implementing a carbon tax that generates ancillary benefits on urban air pollution is not the most cost-efficient way to control these local pollutants. If reducing specific emissions like PM_{10} is the main policy priority, then the best-suited policy option is likely to be different and result in a lower PM_{10} unit reduction cost.

The Dessus and O'Connor study also concludes that local governments may be interested in supporting GHG emission reductions if international finance is available and where such reductions are expected to reduce local externalities. However, it would be difficult to expect a full financial cost compensation if the GHG emission reduction policies are implemented as part of ongoing local air pollution control programme activities.

Policy Approach (3) has been used in a case study for urban air pollution control in New Delhi, which is included in Chapter 5. This study examines tradeoffs and synergies between local and global externalities, with joint local and global externality policies as simultaneous primary policy objectives. The study is a stylised example[25] of how these integrated objectives may be assessed in the context of an air pollution control programme that suggests replacing existing two-stroke three

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[25] The study is constructed on the basis of a mixture of data from Dakar and New Delhi and do not represent a real site specific assessment.

wheelers with alternative technologies. These alternative technologies include four-stroke engines, fuel/oil remix, electronic ignition, engine rebuilding, pump-less lubrication system, periodic inspection and maintenance, phase out of old three-wheelers, and conversion to compressed natural gas (CNG). Most of these alternative technologies benefit both global and local air quality, except for the option to convert to CNG, which reduces PM_{10} emissions but suggests an eventual increase in GHG emissions due to leakage in the CH_4 supply system.

The magnitude of the local and global benefits differs, however. The reduced local PM_{10} equivalent emissions are estimated to generate a benefit of more than $20 million, assuming a unit damage cost of $19,000 per tonne of PM_{10} equivalent. The global benefit of reduced GHG emissions will be very small compared with the local benefit at less than $1 million assuming a unit damage cost of $10 per tonne of carbon.

It should be emphasised again that the assessment of GHG reduction inclusive programme options needs to be integrated with a general cost-effectiveness analysis of the transportation policy programme, and that a comprehensive assessment of the options requires estimates of the performance of all programme objectives – whether relating to general transportation objectives, local environmental goals or global externalities. The evaluation of the policy goals, determined in a dialogue between the donor agency and the local government and other stakeholders, can be related to the following parameters:

- Project or policy costs: capital costs, land cost, fuel costs, labour costs, operation and maintenance (O&M) costs, implementation costs, etc.
- Financial transfer.
- Social impacts: economic development, employment, equity, accessibility, etc.
- Local environmental impacts: airborne pollutants, noise, congestion, accidents, visual impacts, etc.
- GHG emissions.

The form of the cost-effectiveness analysis varies depending on the selected policy goals and the assumptions applied to the baseline case of local environmental externalities. The case studies included in this book are examples of how such cost-effectiveness estimates may be constructed. This recommended general decision-making "rule" to apply a cost-effectiveness analysis for all policy options in relation to all policy goals and parameters can be very demanding in practice because it involves very extensive data collection. In practice it might be best to include only a small number of specific GHG reduction policy elements in transportation programme activities. Elements may, for example, be selected from among options eligible for GEF support (see the list included Chapter 9).

4.3.3 Donor and Host Interests

Successful policy implementation requires that donor and host interests be met. There are, however, a number of critical issues relating to the reconciliation of these interests in GHG reduction inclusive transport policies.

Assessing local development objectives, local and regional environmental goals, and global externalities requires a consistent measurement framework. Donors, however, must use "external" financial resources for the GHG reduction components, for example, from the Global Environmental Facility, that have specific financial rules for project support which may differ from those of the host country.

The GEF case is one of many examples showing that international implementing agencies and programme host countries may have different interests, perspectives, and financial requirements. This will need to be considered and balanced through the programme development and implementation in order to establish successful and sustainable projects.

Implementing Agency Perspectives. Donor-financed transportation programmes are guided by specific sector strategies as well as implementation frameworks for financing climate change, which currently include a number of international co-operative mechanisms defined by the Kyoto Protocol and the GEF Operational Program 11 - as described in Chapter 9.

A singular focus on climate change financing suggests that implementing agencies' central interest should be to minimise risk and financial cost of GHG emission reduction. Other objectives may be considered if the GHG emission projects are integrated in broader programmes. For example, the development agency might prefer to implement GHG emission reduction projects with positive side effects on other programme objectives and try to get part of these financed through specific climate change-related financial mechanisms.

Host Country Perspectives. Host countries may have many different interests in relation to transportation programmes, and these interests may in principle include various stakeholder and government objectives. Such objectives would be selected on the basis of official national development plans as well as specific stakeholder interests.

In some cases local governments may be willing to integrate GHG emission reduction projects with international financial mechanisms, if they are fully compensated for the financial costs of these undertakings and where such projects support local development or environmental policy priorities. For example, with reference to the case studies contained later in this book, this might be the case for projects such as the vehicle maintenance programme for Pakistan and the road pavement project in Chile.

From the preceding sections it is clear that actual policy specification and selection of GHG reduction inclusive projects involves a negotiating process between donor and host parties, starting with evaluation of a number of alternative transportation projects and using available information about associated economic, social and environmental impacts.

4.4 Summary and conclusions

The transportation sector in developing countries is expected to be responsible for rapidly growing GHG emissions over the next twenty to thirty years. Therefore it is important to assess the cost-effectiveness of implementing GHG emission reduction

policies in this sector. GHG mitigation in the transportation sector may be implemented as a part of cross-sectoral programmes designed to support local development and environmental policies. In this case potential GHG emission reduction projects must be considered explicitly in the context that the GHG reductions necessitate trade-offs with these other priorities.

Transportation reform programmes often bring about increased transportation activity resulting in increased GHG emissions. A GHG reduction inclusive policy incorporated in transportation programmes should, however, decrease GHG emissions. In both cases, the actual GHG emissions from the transportation programme can then be calculated by comparing the GHG reduction inclusive policy case to a baseline case without GHG reduction as a policy objective.

As noted before, the World Bank is promoting urban air pollution control programmes in Latin America, Eastern and Central Europe, Africa, and Asia. Many of the transport-related interventions that cities undertake to improve local air quality are likely to have some additional benefits in terms of reducing global environmental externalities. However, some studies suggest that the global environmental benefits may be small compared to the outcome of a combined local air pollution and GHG reduction programme.

Local benefits of transportation sector urban air pollution control programmes are likely to be large. Therefore, local governments may wish to combine the development of such programmes with GHG reduction strategies in order to secure international climate finance that enables both local and global benefits to be realised. Thus, international climate change finance may act as a subsidy in the attainment of other national policy goals, though it should be noted that such an approach will not generally lead to the most cost-efficient regulation from a national point of view.

5. Case studies

5.1 Introduction

This chapter presents five case studies, which employ the main concepts and analytical steps involved in the inclusion of GHG mitigation in project analysis, outlined in earlier chapters. These case studies are:

Urban air pollution control in Delhi, India - this case example examines the extent to which a generic "locally" motivated urban air quality programme and a generic "globally" motivated programme are similar. The primary purpose is to illustrate the trade-offs that often confront the decision-maker when one objective is pursued over the other. Recommendations are made – both in terms of policy measures and analytical frameworks - so as to satisfy both the local and global decision-maker.

A highway project in China - new highway construction projects often facilitate increased transport activity – which is an accepted objective. Increased transportation activities however, generally increase GHG emissions. In this example we consider "complementary" projects, which aim to address the expected increase in GHG emissions, while still maintaining the transportation services created by the highway. Specifically, we consider the simultaneous substitution of older gasoline-powered medium size trucks, which are expected to use the new highway, with new, more efficient diesel-powered trucks. Subject to the global (and regional) air pollution benefits to be realised, there may be a case for linking such projects to the financing arrangements of the infrastructure project.

A road pavement project in Chile – in this case study we examine CHILPAVE, a joint U.S. and Chilean project, designed to introduce new road repair and construction technology to Chile. The technology has lower (life-cycle) energy consumption, and subsequently GHG emissions, relative to existing re-paving methods. The costs and benefits are estimated, including investigation of the GHG impacts.

The introduction of LPG buses in Mauritius - in this case example we examine the costs and benefits of replacing (light) diesel-powered buses in Mauritius with LPG-powered buses. Specifically, we estimate the "social" cost-effectiveness of a proposed replacement programme in abating carbon-weighted GHG emissions. The primary purpose of this case study is to illustrate how the cost-effectiveness of a project changes, as the basis of the cost analysis changes from private to social costs, and to discuss the subsequent implications for developing a mitigation strategy.

An improved vehicle maintenance programme in Pakistan – this GEF-supported project aims to reduce GHG emissions (and other pollutants) by improving the fuel efficiency of (existing and future) road transport vehicles. It seeks to do this by establishing tune-up demonstration and training centres at various locations throughout Pakistan. It is hoped that these centres will help in the development of local capacity in the advanced diagnosis of engine performance, and stimulate a market for these services. In this case study, the costs and benefits of this programme are assessed, including consideration of the impact on GHG emissions.

The **primary objectives** of these case studies are two-fold. First, they illustrate how to use the main concepts in GHG mitigation inclusive policy analysis (e.g. costs, benefits, and scenarios). Second, they demonstrate the analytical framework in which these concepts can be assessed. While each case study may focus more on one concept than another – e.g. the Mauritius case study illustrates the analytical significance of the cost definition adopted – collectively they serve to illustrate the application of concepts and methods used in analysis of GHG mitigation inclusive policies.

These case studies are meant to be illustrative. For example, the Mauritius case study highlights the use of various cost concepts. It does not seek to demonstrate the relative merit of replacing (light) diesel-powered buses with equivalent LPG-powered buses. In line with the stated objective, case study results and data used to derive them should **not** form the basis of policy, although every effort has been made to use the most reliable data available.

Two final case studies look at collaboration with the private sector in bringing about environmental improvements in the transportation sector. The first of these examines **zero-emission vehicles (ZEV)**, whilst the second examines **the European Auto-oil Programme**. We present these case studies to illustrate the potential for private sector collaboration in abating GHG emissions, or for that matter, any air emissions arising from the transport sector.

5.2 Urban Air Pollution Control Programme: The Case of Delhi, India[26]

5.2.1 Introduction

World-wide, poor urban air quality poses one of the most serious threats to human and environmental health. Urban air pollution is produced through the combustion of fuels by power generators, industry, domestic residences and, increasingly, motor vehicles[27]. Fuel combustion not only results in the emission of so-called "local" pollutants[28], but also results in the emission of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Urban pollution control programmes focus primarily on reducing emissions of local air pollutants.

This case study examines the extent to which a generic "local" air quality programme for New Delhi, India, and a generic "global" programme are similar. The primary purpose of the case study is to illustrate the trade-offs that often confront the decision-maker when comparing programmes with different objectives.

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[26] This case example draws heavily on the paper by Xie, Shah and Brandon (1998), "Fighting Urban Transport Air Pollution for Local and Global Good: The Case of Two-stroke Three-wheelers in Delhi".

[27] See, for example, Onursal and Gautam (1997).

[28] The main local air pollutants are particulate matter less than ten microns in diameter (PM_{10}), aerosols of sulphur oxides (SO_x) and nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO) and lead (Pb).

5.2.2 The Business-As-Usual Case

Before examining measures to reduce emissions from motor vehicles (as part of a wider urban air pollution control programme), a baseline emission inventory must be established against which the performance of the technical abatement measures, proposed under the economically efficient transport reform case, may be judged.

The vehicle population in New Delhi is dominated by two- and three-wheeler vehicles, which account for 69 percent of the total stock of about 2.76 million units[29]. The majority of these two- and three-wheelers have two-stroke engines. This has important consequences for urban air quality since, unlike four-stroke engines, two-stroke engines do not have distinct intake and exhaust strokes. As a result, relative to four-stroke engines of similar size and power, two-stroke engines have markedly higher PM, CO and HC emissions. Therefore the focus of this case study is on two-stroke engine vehicles (TSEV). Moreover, to keep the presentation simple, the analysis is restricted to the three-wheel variety.

A preliminary inventory of air emissions in New Delhi reveals that motor vehicles in total emit about 21,500 tonnes of PM_{10}, 100,000 tonnes of HC and 279,400 tonnes of CO annually (Xie *et al*, 1998 and own calculations based on UNEP, 1999). The share of three-wheel TSEVs in total vehicular emissions of PM_{10}, HC and CO is approximately 8 percent (1,685 tonnes), 26 percent (25,800 tonnes) and 15 percent (41,300 tonnes), respectively.

5.2.3 The Transport Reform Case

In this section, a number of possible technical measures to control air emissions from three-wheel TSEVs are examined. These include periodic inspection and maintenance, installation of pumpless lubrication systems, conversion to CNG vehicles and phase out of old three wheelers, amongst others. Specifically, the cost-effectiveness of the selected measures in abating PM_{10} equivalents is determined[30]. It is assumed that these measures form part of an initiative to reduce the emission of local air pollutants. Table 5.1 shows the environmental performance of the selected measures, in terms of their effectiveness in reducing baseline emissions of PM_{10}, HC and CO[31], as well as the estimated change in fuel economy associated with each measure.

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[29] In 1996 there were approximately 80,200 three-wheel vehicles and 1.82 million two-wheel vehicles.

[30] See Eskeland (1994) for an explanation of the use and determination of PM_{10} equivalents.

[31] The measures contained in Table 5.2 are only examples of possible options – the list is not intended to be exhaustive – only illustrative.

Table 5.1 Environmental performance of selected control measures for two-stroke three-wheelers: Percentage change in baseline emission factors

Abatement measure	PM_{10}	HC	CO	Fuel economy
	(%)	(%)	(%)	(%)
Baseline emission factors (g/km)	0.50	7.65	12.25	20 km/l
Periodic I & M	-20	-20	-35	+5
Pumpless Lubrication System (PLS)	-80	0	0	+3
Engine rebuilding	-30	-40	-50	+5
Phase out of old three-wheelers	-100	-100	-100	-
Fuel/oil premix	-30	-10	0	+3
Convert to CNG vehicles	-80	+10	-88	n/a
Replace with 4-stroke vehicles	-80	-90	-100	+20

Source: Energy and Environmental Analysis, Inc (1998) and others in Xie *et al* (1998).

Note:
The environmental performance and costs of these measures (shown in Table 5.2 below) were originally estimated for Dhaka. For the purpose of this case study we are simply applying the data set directly to the three-wheel TSEV stock of Delhi.

Table 5.2 shows the results of the cost-effectiveness analysis, where the measures are ranked in order of increasing (unit) private costs. One can see that five of the seven measures considered represent so-called "win-win" measures, i.e. measures that, through their cost savings to vehicle owners, are economically justified in their own right.

Table 5.2 Cost-effectiveness of selected measures in abating 'local' pollutants

Abatement measure	Percentage of fleet affected[1]	Annual emission savings	Net annual cost	Net abatement cost
	(%)	(t PM_{10} eq./year)	($ million / year)	($/t PM_{10} eq.)
Convert to CNG vehicles[2]	30	540	-6.2	-11,500
Replace with 4-stroke vehicles	10	300	-2.7	-9,000
Fuel/oil premix	30	180	-0.5	-3,000
Engine rebuilding	30	370	-0.8	-2,200
Pumpless Lubric. System (PLS)	50	670	-1.4	-2,100
Periodic I & M	100	760	+1.3	+1,700
Phase out of old three-wheelers	17	570	+3.1	+5,400

Source: Adapted from Xie *et al* (1998)
Notes:
1 The percentage of the entire fleet affected by the technology is based on preliminary judgments by Xie *et al* (1998). They are therefore subject to change and are purely illustrative.
2 The costs here only relate to retrofitting the vehicles, they do not include the cost of providing the supply and re-fuelling infrastructure. At present Delhi has nine CNG filling stations, although a Supreme Court order is in place to expand the distribution network to 80 stations (UNEP, 1999).

The results in Table 5.2 were used to construct a preliminary abatement cost curve (shown in Figure 5.1). In constructing the curve, the simplifying assumption is made

that measures continue to be implemented until 100 percent of the fleet is modified[32]. The curve indicates that just over 42 percent of total emissions (or 1,390 t PM_{10} eq.) from three-wheel TSEVs can be abated at no incremental costs[33]. Indeed, vehicle operators will accrue annual savings of some $ 10.2 million.

Figure 5.1 Preliminary Abatement Cost Curve for Two-stroke Three-wheelers in Delhi

Emission Reduction (% of total PM10 eq. emissions from 2-stroke 3-wheelers)
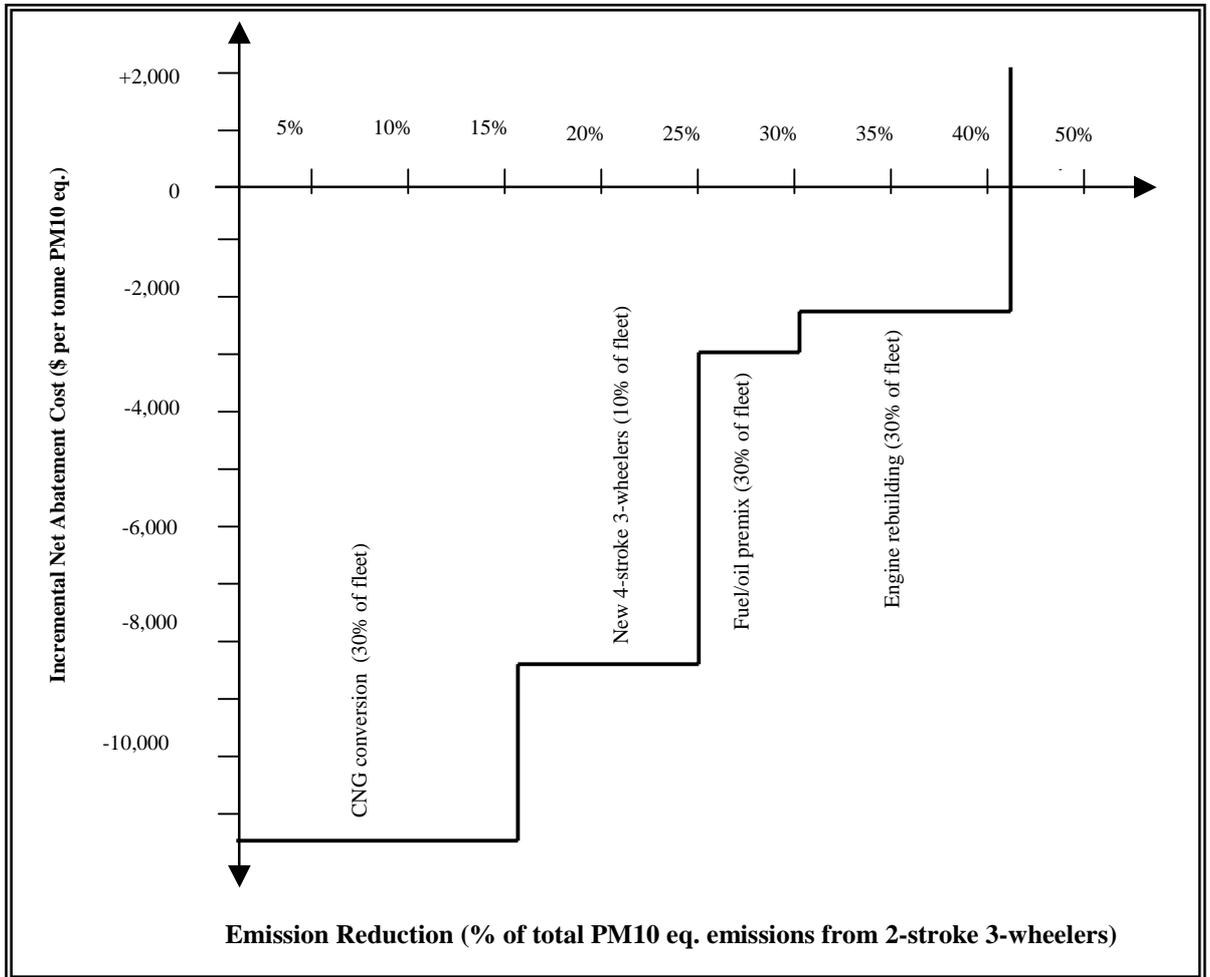
5.2.4 The GHG Reduction Case

Under the Business-as-Usual case, estimated annual GHG emissions for three-wheel TSEVs are: 390,800 t CO_2; 505 t CH_4; and 7 t N_2O. Using the GWP for CH_4 and N_2O

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[32] It is important to realise that cost curves like the one shown in Figure 5.1, which are based on the **partial solutions** approach to construction, do not take into account interactions between measures, e.g. whether measures may be implemented in parallel or sequence. Consequently, the environmental performance of the listed measures may not be strictly additive. Curves based on this approach nonetheless represent a valid starting point for developing a mitigation strategy; they show broad relationships between emission reduction potentials and the cost of those reductions.

[33] Specifically, converting 30 percent of the three-wheeler fleet to CNG saves 540 t PM_{10} eq. per year, replacing 10 percent of the fleet with new 4-stroke engine vehicles saves 300 t PM_{10} eq. per year, changing the fuel/oil premix in 30 percent of the fleet saves 180 t PM_{10} eq. per year, and rebuilding the engine in the remaining 30 per cent of the fleet saves 370 t PM_{10} eq. per year.

recommended by IPCC (1996a) for a timeframe of 100 years (i.e. 24.5 and 320 respectively), three-wheel TSEVs in New Delhi emit about 405,300 tonnes CO_2 equivalent annually.

No data on the effectiveness of the selected measures (assumed to be implemented under the transport reform case) in abating GHGs are available; data are only available on the collateral improvements in fuel economy. Hence, the contribution of each measure to GHG reductions is approximated by assuming that an improvement in fuel economy will result in a proportional reduction in CO_2 emissions[34]. Table 3 shows the cost-effectiveness of the selected measures in abating GHG emissions, ranked in ascending order[35]. Again, the majority of the considered measures represent "win-win" situations.

If the measures listed in Table 5.3 are implemented in order of least-cost, until 100 percent of the fleet is affected – as they might be if the policy objective was to address global externalities - nearly 5 percent of total CO_2 eq. emissions from three-wheel TSEVs could be abated at no incremental costs[36]. In this case vehicle operators accrue annual savings of just under $ 4.9 million.

Table 5.3 Cost-effectiveness of selected technical measures in abating GHGs

Abatement measure	Percentage of fleet affected	Annual emission savings	Net annual cost	Net abatement cost
	(%)	(t CO_2 eq./year)	($ million/year)	($/t CO_2 eq.)
Replace with 4-stroke vehicles	10	-7,800	-2.7	-345
Pumpless lubric. system (PLS)	50	-5,900	-1.4	-235
Fuel/oil premix	30	-3,500	-0.5	-145
Engine rebuilding	30	-5,900	-0.8	-135
Periodic I & M	100	-19,500	+1.3	+65
Phase out of old three-wheelers	17	-66,500	+3.1	+45
Convert to CNG vehicles	30	+189,200	-6.0	--

Source: Adapted from Xie *et al* (1998)

Notes:

A '+' indicates an overall increase in emissions; conversely a '-' indicates an overall decrease in emissions. Only the CNG conversion measure considers GHG emissions other than CO_2. To the extent that CH_4 and N_2O are also reduced by the other measures, the estimated net abatement cost will be overestimated.

CNG vehicles are assumed to generate increased CO_2 equivalent emissions because the present gas supply system is expected to have major leakages in the form of CH_4 emissions.

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[34] It is not appropriate to extend this approximation to CH_4 and N_2O emissions. Changes in emissions of these two pollutants is only considered for switching to CNG vehicles, for which estimates of reduction efficiencies were available.

[35] The same caveat applies regarding the failure to consider interactions between measures.

[36] Specifically, replacing 10 percent of the three-wheeler fleet with new 4-stroke engine vehicles saves about 7,800 t CO_2 eq. per year, installing a PLS in 50 percent of the fleet saves 5,900 t CO_2 eq. per year, changing the fuel/oil premix in 30 percent of the fleet saves 3,500 t CO_2 eq. per year, rebuilding the engine in the remaining 10 percent of the fleet saves 1/3rd of 5,900 t CO_2 eq. per year. In total, these four measures thus save around 19,200 t CO_2 eq. per year.

5.2.4.1   Comparing the Transport Reform and GHG Reduction Cases

Given a purely locally motivated policy objective, which would see the transport reform programme implemented (i.e. the first four measures in Table 5.2 are undertaken, in sequence, until 100 percent of the fleet is affected) total GHG emissions would actually increase by 172,000 tonnes CO_2 eq. per year (i.e. by 42 percent):

Global Consequences of "Local" Programme:

Convert to CNG vehicles (30 % of fleet)	+189,200 t CO_2 eq. per year
Replace with 4-stroke vehicles (10 % of fleet)	-7,800 t CO_2 eq. per year
Fuel/oil premix (30 % of fleet)	-3,500 t CO_2 eq. per year
Engine rebuilding (30 % of fleet)	-5,900 t CO_2 eq. per year
Total change in GHG emissions (100 % of fleet)	+172,000 t CO_2 eq. per year

If, instead, the decision-maker pursued a purely global objective (sequentially implementing the first four measures in Table 5.3), reducing CO_2 eq. emissions by nearly 5 percent, total local (weighted) pollutants are reduced 38 percent (1,270 t PM_{10} eq.). This is only slightly less than the savings realised under the purely locally focused, transport reform programme – i.e. 42 percent (1,390 t PM_{10} eq.).

Local Consequences of "Global" Programme:

Replace with 4-stroke vehicles (10 % of fleet)	-300 t PM_{10} eq. per year
PLS (50 % of fleet)	-670 t PM_{10} eq. per year
Fuel/oil premix (30 % of fleet)	-180 t PM_{10} eq. per year
Engine rebuilding (10 % of fleet)	-120 t PM_{10} eq. per year
Total change in GHG emissions (100 % of fleet)	-1,270 t PM_{10} eq. per year

5.2.4.2   Cost-Benefit Analysis of "Local" and "Global" Abatement Programmes

In this section a simplified cost-benefit analysis (CBA) is undertaken to further compare the "local" (transport reform) case and the "global" (GHG mitigation) case. Table 5.4 shows results of the CBA. Clearly, both programmes yield substantial annual net annual benefits. The total net annual benefit estimates however, mask the fact that the transport reform programme actually imposes a global (external) cost burden.

If the primary objective were to reduce GHG emissions (i.e. pursue a "globally" motivated objective), annual net benefits would decline by $ 5.7 million relative to the transport reform case. In other words, the opportunity cost of pursuing a "globally" motivated objective is $ 5.7 million per year. At the same time however, the net difference in GHG emissions between the two cases is +190,400 t CO_2 eq. per year (i.e. 171,200 t CO_2 eq. + 19,200 t CO_2 eq.). Hence, if the decision-maker opted to focus solely on GHG emission reductions, the opportunity cost of doing so is nearly $ 30 per t CO_2 eq. (i.e. $ 5.7 million ÷ 190,400 tonnes of CO_2 eq.), which exceeds the

central benefit (damage cost avoided) estimate of $10 per tonne CO_2 eq. Hence, the opportunity cost of forgoing the transport reform programme is not justified in this case.

Interestingly, by not implementing the transport reform programme, $ 7.6 million per year in "local" benefits are foregone ($ 37.3 - $ 29.7 from line 4 in Table 5.4) – of which, $ 5.3 million would accrue directly to the operators of three-wheel TSEVs; only $ 2.3 million (in the form of health benefits) would accrue to the local population as a whole. Hence, the trade-off in this case is primarily between vehicle operating cost savings and avoided global warming damages.

Table 5.4 A Simplified CBA of "locally" and "globally" motivated control programmes

	Local Objective (Transport Reform)	Global Objective (GHG Reduction)
1. Cost of 'least-cost' programme ($ mn / year)	-10.2	-4.9
2. Change in PM_{10} eq. emissions (tonnes / year)	-1,390	-1,270
3. Unit damage cost ($ / tonne PM_{10} eq.) [1]	19,500	19,500
4. Local benefits (2 * 3 + 1) ($ mn / year)	-37.3	-29.7
5. Change in CO_2 eq. emissions (tonnes / year)	+171,200	-19,200
6. Unit damage cost ($ / tonne CO_2 eq.) [2]	10	10
7. Global warming benefits (5 * 6) ($ mn / year)	+1.7	-0.2
8. Annual net benefit (4 + 7) ($ mn / year)	-35.6	-29.9

Notes:
[1] PM_{10} emissions from TSEVs could result in at least 1,400 premature deaths, 12 million restricted activity days and 38 million respiratory symptoms per year. The estimated economic cost of these health effects is about $ 122 million (Xie *et al*, 1998). This is equivalent to about $ 19,537 per tonne of PM_{10}.
[2] The global benefits of the above control programmes are valued using the range of unit damage costs suggested by Delucchi (1998). After a review of the literature on climate change damages, the most reasonable range of damage cost estimates was judged to be between $ 2 per tonne CO_2 and $ 20 per tonne CO_2, with most of the estimates tending towards $ 10 per tonne CO_2.

5.2.4.3   Improving Synergy between "Local" and "Global" Programmes

In this case study the transport reform program imposes a global burden, solely as a result of increased CH_4 emissions from implementing the CNG conversion option. If the increase in GHG emissions associated with this option result from fugitive CH_4 emissions from the distribution network[37], it may be feasible to implement an additional project to reduce these emissions. This in turn would improve the "global" performance of the CNG conversion option and of the "local" program as a whole, but at additional cost. Data limitations prevent us from re-working the cost-effectiveness calculations reported above, including a "CNG plus additional CH_4 abatement option," however rough data from an International Energy Agency (IEA) report (ECOFYS, 1997) allows us to conduct a "break-even" analysis.

ECOFYS (1997) estimates that reducing GHG emissions from natural gas distribution networks – using various types of I & M programs - range from US$ 75 to US$ 150 per abated tonne CO_2 eq. Using these unit costs, we estimate that CH_4 abatement is possible, to the point at which the annual net benefits of the "local" program are equal

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[37]   From the data set on which the case study is based, it is not possible to ascertain whether this is actually the case.

to those of the "global" program. Table 5.5 summarizes the results of the calculations. With the lower abatement cost of US$ 75 per tonne CO_2 eq., for example, an I & M program costing US$ 5.1 million per year could be initiated in addition to the local abatement programme. GHG emissions would decline by 66,600 tonnes of CO2 eq. Annually, maintaining and the global program's overall annual net benefits.

This example illustrates the potential to wholly satisfy local interests and partially satisfy the global interests:

- The least-cost "local" program remains intact, but additional GHG abatement measures are implemented;

- The "global" program's annual net benefits are still realized.

Hence, there may be a case for global decision-makers to partially fund "add-on" measures to local air pollution abatement programs. To this end the simple framework shown in Table 5.5 concept may serve as a useful input to policy negotiations.

Table 5.5: Simplified CBA of "locally" motivated control program with additional abatement on fugitive methane emissions (CNG supply)

	Fugitive emission abatement	Fugitive emission abatement
	($ 75 / t CO2 eq.)	($ 150 / t CO2 eq.)
1. Cost of 'least-cost' program ($ mn / year)	-9.0	-9.0
2. Change in PM_{10} eq. emissions (tonnes / year)	-1,430	-1,430
3. Unit damage cost ($ / tonne PM_{10} eq.)	19,500	19,500
4. Local benefits (2 * 3 + 1) ($ mn / year)	-36.9	-36.9
5. I & M fugitive missions CNG ($ mn / year)	+5.1	+4.7
6. ΔCO_2 eq. - I & M fugitive missions (tonnes / year)	-66,660	-30,950
7. ΔCO_2 eq. emission relative to BAU (tonnes / year)	+171,200	+171,200
8. Net ΔCO_2 eq. (6 + 7) (tonnes / year)	+104,540	+140,250
9. Unit damage cost ($ / tonne CO_2 eq.)	10	10
10. Global warming benefits (8 * 9) ($ mn / year)	+1.0	+1.4
11. Annual net benefit (4 + 5 + 7) ($ mn / year)	-30.8	-30.8

5.2.4.4   Further Improving Synergy between "Local" and "Global" Programmes

In our simplified example, implementing the least-cost GHG abatement program yields a global benefit with a small loss in overall annual net benefits (with a relatively smaller sacrifice in local health benefits). The fact that the program partly achieves both local and global benefits is essentially a result of the measures considered having a positive impact on fuel economy. Reducing the amount of fuel consumed per kilometer traveled, *ceteris paribus*, will reduce total air emissions. Of course, this assumes no change in travel demand, which is a questionable assumption

if short-term running costs are likely to decrease[38]. Therefore, the potential for an urban air pollution control program to yield collateral global benefits, is enhanced if:

1. Measures reduce fuel consumption or result in a shift towards less carbon-intensive fuels; and

2. Travel demand is simultaneously controlled.

In a study of Santiago, Eskeland and Xie examined these propositions (Eskeland and Xie 1998), and found that a carbon tax on fuel not only suppressed travel demand resulting from fuel efficiency savings, but also modestly increased locally weighted emission reductions. For example, a carbon tax of $150 per tonne C (equivalent to 10 cents per litre of gasoline), caused reductions in total PM_{10} eq. emissions from 61 percent to 71 percent, albeit at higher marginal costs. In terms of global benefits, a carbon tax at the same level achieved a 29 percent reduction in total GHG emissions; the technical standards alone only achieved a 5 percent reduction. Moreover, a carbon tax, even at this relatively high level, had lower marginal abatement costs than the 'least-cost' emission standard.

5.3 Highway Project in China

5.3.1 Introduction

New donor-financed highway construction projects often lead to increased transport activity, as well as reduce travel time and freight costs. But increased transportation activities generally increase GHG emissions (and other emissions). "Complementary" projects, which address these expected emission increases, represent a feasible GHG mitigation project. Such policy options include the creation of alternative modes like railways or the introduction of vehicles with lower GHG emissions. The railway option could be argued to represent a "substitute" project (as opposed to an additional, "complementary" project), and that a GHG mitigation objective does not justify such a "radical" change in the infrastructure project. The range of "complementary" mitigation projects that can be integrated into infrastructure projects are limited. Furthermore, demand-side management measures are difficult to use because they mitigate transportation activity, an accepted objective of such highway projects.

Projects such as the introduction of vehicles with lower GHG emissions, which are consistent with the main objectives of the infrastructure project, are likely candidates for consideration as transport-related GHG reduction inclusive policies. Introduction of lower emission vehicles is argued to be a stand-alone project, not requiring a link to the infrastructure project. There may be a case for linking such projects to the financing arrangements of the infrastructure project, subject to the global (and regional) air pollution benefits.

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[38] It is more than likely that these measures, which improve fuel efficiency and thereby reduce running costs, will actually increase demand. To the extent that this is true, the emission savings estimates given above are probably upwardly biased.

This case study considers, as a possible project, substituting "older" gasoline-powered medium size trucks, which are expected to use a new highway in China, with new, more efficient diesel-powered trucks. The case study is based on material contained in Hagler Bailly (1998) and He *et al* (1994).

5.3.2   Baseline case (Transport reform case)

5.3.2.1   Background to highway project

The Chinese highway project considered here is a part of the larger China National Highway Project. This case study considers development of National Highway 107, a key element of the national truck highway system in the principal north-south corridor. The estimated cost of the highway component is $US 524 million – 50% of which is to be financed by the World Bank (Hagler Bailly, 1998).

Major assumptions used in this project assessment are:

- The total traffic volume on the highway will increase from 300,400 vehicles per day without the project to 434,000 vehicles per day with the project in 2010.

- The structure of the vehicle fleet (with and without the project) is:
    o 30% long-haul freight vehicles with an average driving distance of 340 km per trip,
    o 35% short-haul freight vehicles with an average driving distance of 61 km per trip, and
    o 35% passenger vehicles with an average driving distance of 45 km per trip.

- The GHG emission factors of the different vehicle types are:
    o long-haul vehicles: 317 grams carbon per km,
    o short-haul vehicles: 317 grams carbon per km, and
       passenger vehicles: 127 grams carbon per km.

- The new highway is expected to enable fuel economy savings of around 10%, due to better driving conditions compared with the old highway.

(Source: World Bank Staff Appraisal Report based on Hagler Bailly, 1998).

Hagler Bailly (1998) and He *et al* (1994) forecast activity increases, CO_2 emissions for the total project and for medium size trucks. Table 5.6 shows these forecasts that define the Transport Reform case, which in turn serves as the Baseline Case for the GHG reduction inclusive policy. Annual CO_2 emissions under the Baseline (Transport reform) case are about 1.5 million tonnes of carbon (C), with the highway project expected to increase annual carbon emissions by about 0.34 million tonnes C in the year 2010.

Table 5.6 Forecast of traffic and carbon emissions for 2010 in the Baseline case and the GHG reduction inclusive policy case

Case	Total vehicles	Total distance	CO_2 emissions
	(number per day)	(km per year)	(Mn t C per year [1])
Business-as-Usual (without highway)	300,400	3,870.8	1.14
Transport Reform (with highway)	434,000	5,573.9	1.48

Notes:
[1] The highway is assumed to imply a 10% efficiency improvement in fuel consumption that is reflected in the CO_2 emission calculation.

5.3.3 The GHG reduction case

Addressing the increase in GHG emission in the Transport Reform Case, the GHG reduction case considers replacing 50% of medium size gasoline trucks used in 2010 with diesel trucks. Annual emission savings, the global benefit, are estimated for 2010 only.

5.3.3.1 Technical Characteristics of Medium Size Trucks

As much as two thirds of the traffic on the Chinese highway project is expected to be freight transport, with a significant part of this traffic being medium size gasoline trucks, which consume more fuel than diesel trucks. Despite attractive fuel cost savings, the introduction of diesel trucks, in China as well as in a number of other developing countries, has been constrained by high up front investment costs needed to establish diesel fuel supply and engine and vehicle manufacturing infrastructure.

The gasoline trucks currently used in China are very inefficient, consuming great quantities of fuel and producing huge GHG emissions. The He *et al* study (1994) assessed the energy efficiency potential and cost of retrofitting medium size trucks with diesel engines in China. The study includes data on vehicle stock structure, fuel intensity, and costs of engine retrofitting. Box 5.1 summarises the study's main assumptions.

Diesel trucks likely will have a larger NO_x and particulate emissions per unit of fuel consumption than gasoline trucks, resulting in their having a negative impact on the local and regional environment.

Box 5.1 Main assumptions on Chinese medium size trucks applied to the GHG reduction inclusive policy case

It is technically feasible to substitute gasoline engines with diesel engines in medium size trucks (the dimensions and weight of the diesel engines are about the same as the gasoline engines, and the finished products are available).

The investment cost of retrofitting a gasoline truck with a diesel engine will be 1,690 Yuan (using 1994 prices).

The fuel intensity of a diesel truck is 35% lower than the intensity of a gasoline truck.

Medium size gasoline trucks will be 78% of all trucks in 2010 and their total driving distance will be 26% of the distance of all trucks.

5.3.3.2   GHG reduction inclusive Costs and Benefits

Table 5.7 shows the estimated 2010 GHG emission reductions under the GHG reduction inclusive case. This policy results in an emission reduction of 60,000 tC in 2010, which is a 15% decrease in total carbon emissions from medium size trucks.

Table 5.7 GHG Reduction Case - Forecast of Traffic and Carbon Emissions from Medium Size Trucks in 2010

Case	Number of medium size gasoline trucks [1]	Annual driving distance of medium size gasoline trucks [2] (million km)	Number of gasoline trucks substituted with diesel	Annual driving distance of substituted trucks (million km)	GHG emissions all medium size trucks (million t C)
Baseline (Transport Reform)	338,520	1,232.4	-	-	0.39
GHG Reduction-Inclusive	169,260	616.2	169,200	616.2	0.33 [3]

Source: He *et al* (1994).
Notes:
[1] Based on the composition of the vehicle stock.
[2] Assumed to be 26% of all km travelled by trucks.
[3] Includes expected fuel efficiency improvements of 35 % gained by introducing new, fuel-efficient diesel trucks.

The annual incremental costs of introducing medium size diesel trucks relative to sustained use of gasoline trucks is considered by He *et al* (1994) to be 1,690 Yuan per truck[39]. The total annual mitigation capital cost is:

169,200 trucks x 1,690 yuan per truck per year = 285.4 million Yuan per year.

This is equivalent to 4,760 yuan per tC abated (or $US 820 per tC – using the 1994 annual average exchange rate).

He *et* al (1994) suggests that these investment costs will be offset by fuel cost savings, but that the magnitude of this saving depends on truck driving activity as well as on fuel prices. They estimate, for example, an annual fuel cost saving of 5,300 yuan (based on 1990 fuel prices and an annual driving distance of 30,000 km). If these savings were realised, the annual investment costs would be completely offset – i.e. the project would represent a "win-win" option. However, potential annual fuel cost savings is not included in the current cost calculations.

5.3.4   Summary of the Highway Project GHG Reduction Inclusive Project

The Transport Reform Chinese highway project considered herein leads to increases in transportation activity and subsequently GHG emissions. The project is estimated to generate an annual increase in carbon emission of 0.34 million t C in 2010. Part of this increase, namely 0.06 million tC, can be abated if the highway project is complemented by a GHG mitigation project, in this case - substitution of 50% of the expected medium size gasoline trucks on the new highway system with more efficient, diesel fuelled trucks. The annual investment of retrofitting the gasoline trucks with diesel engines is estimated to be 285.4 million yuan, equivalent to about $US 820 per abated tC, which is much higher than most benefits of abating carbon. These investment costs likely will be reduced, possibly completely offset, if annual fuel cost savings are included in the cost analysis.

5.4 Road Pavement in Chile: CHILPAVE

5.4.1   Introduction

CHILPAVE is an AIJ project proposed by U.S. and Chilean developers. The project would introduce a new road repair and construction technology to Chile, which would reduce (life-cycle) energy consumption and GHG emissions. The new technology, called "cold mix-in-place recycling" reuses existing distressed asphalt concrete surface and base course materials providing a rehabilitated and greatly strengthened element in new pavement. Using decaying roads to build new roads reduces manufacturing and transportation energy use, substantially reducing emissions. Most paved roads in Chile are in very poor condition. Given, in addition, the fast-growing Chilean economy, a rapid increase in road maintenance and rehabilitation, new construction is expected in the coming years, all of which paves the way for the introduction of CHILPAVE.

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[39]   This includes the cost of retrofitting gasoline trucks with diesel engines, but does not include the costs of establishing increased diesel supply. The potential for increased diesel supply in China is discussed in more detail in He *et al* (1994).

5.4.2 Technology Overview: Hot Mix vs. Cold Mix-in-Place

Cold mix-in-place asphalt concrete road construction uses little newly manufactured emulsified asphalt to bind a mixture of crushed, recycled asphalt concrete surface and base course materials. The recycled asphalt pavement and baseline course layer are treated with emulsions and compacted in-place on the roadway. The process does not require heat.

Chile's only road upgrading alternative is demolishing and discarding the old pavement and replacing it with new paving using traditional hot mix asphalt concrete construction technology, which requires energy (and emits GHG) at ten stages:

1. Extract crude oil;
2. Transport crude oil from exporting country to Chile;
3. Produce asphalt cement from crude oil;
4. Transport the asphalt cement from the refinery to the asphalt concrete mixing plant;
5. Transport the aggregate to the mixing plant;
6. Mix the asphalt concrete at the plant;
7. Transport the asphalt concrete to the job site;
8. Spread and compact the asphalt concrete to reconstruct the wearing surface;
9. Produce, transport and place the replacement aggregate for the base and sub-base; and
10. Remove and dispose of the distressed asphalt concrete pavement, base, and sub-base.

By contrast, the cold mix-in-place asphalt concrete construction technology requires energy at five stages:

1. Produce the asphalt emulsion (only a relatively small quantity is necessary);
2. Transport the asphalt emulsion to the job site;
3. Crush, mix, spread, stabilize, and re-compact the distressed asphalt concrete, the base course, and sub-base materials in place;
4. Manufacture and transport materials for the surface wearing course; and
5. Construct the surface-wearing course.

5.4.3 Impacts on GHG emissions

Calculating GHG reduction inclusive project costs and benefits requires a specific quantitative baseline (Business-as-Usual or Transport Reform) Case and a GHG Reduction Inclusive Case. For CHILPAVE, the Baseline Case includes demolishing and disposing of existing distressed pavement, reconstructing using hot mix asphalt concrete, and replacing existing base and sub-base materials[40]. The GHG Reduction Case proposes the cold mix-in-place technology. Both cases assume a two-lane 7 km long road.

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[40] Hence, in this case study since there is no Reform Case, the Baseline Case is therefore given by the Business-as-Usual Case.

The GHG reduction project will reduce consumption of two types of energy: (1) electrical energy; and (2) diesel fuel. Electrical energy consumption will decrease as demand for manufactured asphalt cement and aggregate decreases, and as a result of decreased operations at the asphalt concrete mixing plants. Diesel fuel consumption will decrease by reducing the use of vehicles and equipment used to transport materials, aid in construction, and dispose of material from the existing roadways.

5.4.3.1   *GHG reduction inclusive Costs and Benefits*

Table 5.8 shows that for each kilometre of road construction, the project reduces CO_2 emissions by 236 tonnes. CHILPAVE reduces total costs by about $US 130,000 over the Baseline case. In this case, the project represents a "win-win" situation in that cost savings of about $US 550 is realized for every tonne of CO_2 abated.

As the project reduces energy consumption, it will also produce secondary environmental benefits. In addition, the technology reduces environmental disruptions associated with mining raw materials and the disposing distressed roadways materials.

The weight and volume of roadway materials are calculated for the three layers (asphalt concrete, base and sub-base) in the pavement structure, for both the GHG reduction inclusive and Baseline cases. Then the quantity of energy consumed for each of five energy use categories is estimated, an extrapolation for energy use in each category is carried out, given the quantities of materials used. Finally, GHG emissions are calculated for the various components of the Baseline and GHG reduction inclusive case using emissions factors. Table 5.9 below shows the estimated emissions associated with each of the five energy use categories. Costs per ton of carbon abated are negative, making the project a "no-regrets" or "win-win" one.

Table 5.8 CO$_2$ Emissions for Baseline case and GHG reduction inclusive case (CO$_2$ in tonnes per km)

	Manufacturing			Demolition			Transportation to mix plant			Transportation to construction site			Construction operations		
	Baseline	Policy Case	GHG Benefit	Baseline	Policy Case	GHG Benefit	Baseline	Policy Case	GHG Benefit	Baseline	Policy Case	GHG Benefit	Baseline	Policy Case	GHG Benefit
Wearing surface	109	45	-64	59	-	-	6	3	-3	16	7	-9	3	1	-2
Aggregate base	20	-	-	0	-	-	15	-	-	24	-	-	4	-	-
Aggregate sub-base	20	-	-	6	-	-	-	-	-	24	-	-	4	-	-
Recycled base	-	5	-	-	4	-	-	6	-	-	-	-	-	4	-
Subtotal	149	50	-99	65	4	-61	21	9	-12	64	7	-57	11	5	-6

Notes:
Total carbon dioxide emissions in Baseline Case = 311 tonne CO$_2$ per km.
Total carbon dioxide emissions in GHG reduction inclusive Case = 75 tonne CO$_2$ per km.
Total carbon dioxide emissions saved – i.e. the GHG reduction inclusive case = 311 – 75 = 236 tonne CO$_2$ per km.

Table 5.9 Emissions and Costs in the Baseline Case and GHG reduction inclusive Case

Scenario	Emissions per km	Cost per km
	(CO_2 in metric ton)	(Present value in 1999 $US)
Baseline case	311	200,000
GHG reduction inclusive case	75	70,000
GHG reduction inclusive benefit and cost	-236	-130,000

Notes:
All emission and cost estimates provided represent the "best" estimates of project developers.

5.5 Introducing Alternative Fuel Buses in Mauritius

5.5.1 Introduction

Rising petroleum prices and increasing concern over adverse human health and environmental impacts of air pollution have led to alternative, cleaner-burning fuels for the transport sector. Major alternative fuels include compressed natural gas (CNG), liquefied petroleum gas (LPG), ethanol, methanol and electricity. Other alternative fuels are vegetable oils, hydrogen, synthetic liquid fuels, and gasohol. In this case study we examine the costs and benefits of replacing (light) diesel-powered buses in Mauritius with original equipment manufacture (OEM) LPG-powered buses. Specifically, we estimate the "social" cost-effectiveness of a replacement programme to abate carbon-weighted GHG emissions. We use the term "social" to refer to **social costs** as opposed to purely **private** (financial) **costs**. For example, we combine the value of emissions savings and the social costs of avoided unemployment with the financial costs of the proposed programme.

This case study illustrates how a project's cost-effectiveness changes, as the cost analysis changes from private to social costs, and discusses developing a mitigation strategy[41].

5.5.2 The Baseline Case

This section defines the Baseline case, against which the environmental and economic performance of the new LPG-powered bus fleet will be evaluated – i.e. the GHG

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[41] The purpose is not to demonstrate the relative merit of replacing (light) diesel-powered buses with equivalent LPG-powered buses. Moreover, the analysis presented below is only applicable to the particular circumstances that prevailed in Mauritius when the data was collected.

reduction inclusive case[42]. This requires us to: (1) establish a baseline emission inventory for the diesel-powered bus fleet to be replaced; and (2) collect data relating to the annual costs of operating this fleet.

Air emissions are the product of an emission factor and an activity statistic. The activity statistic used in this case example is the number of km travelled per vehicle per year. The total operational bus fleet in Mauritius (as of June 30th 1995) was 1,767 buses (CSO, 1997). In total, the fleet made 4,074,000 journeys (trips) in 1995, driving a total distance of 80,736,000 kilometres. Thus, each bus travelled an average yearly distance of about 45,700 km. The product of this activity statistic and emission factors, expressed as emissions per km per bus, provides an estimate of "emissions per bus per year"[43].

Alternative fuel technology is generally "most" cost-effective for commercial fleets because they operate from a few central depots and have high annual mileage (Faiz, *et al*, 1996). This means that the large-scale introduction of LPG-powered buses in Mauritius is most feasible for the country's four major bus fleet operators. These four bus companies operated 880 vehicles in Mauritius in 1995. Total annual emissions of pollutant *x* are the product of emissions of *x* per bus per year and (multiplied by) the number of buses that will eventually be replaced, which is 880 vehicles. Table 5.10 shows the results of these calculations. The emission inventory shown in this table is the Baseline case against which the environmental performance of the LPG-powered buses will be evaluated (under the GHG reduction inclusive case).

Table 5.10 Annual air emissions from main bus fleet in Mauritius (1995)

Pollutant	Emissions: Bus (tonnes / year)	Emissions: Fleet (tonnes / year)
Carbon dioxide (CO_2)	33.4	29,412
Methane (CH_4)	0.004	3
Nitrous oxide (N_2O)	0.002	1
Carbon monoxide (CO)	0.5	413
Nitrogen oxides (NO_x)	0.4	320
Particulate matter (PM_{10})	0.09	80
Non-methane volatile organic compounds (NMVOC)	0.09	76
Sulphur dioxide (SO_2)	0.01	9

Source: Markandya and Boyd (1999)

Notes:
The numbers in columns II and III have been rounded.

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[42] Again, in this case study there is no Transport Reform case, the Baseline case is therefore given by the Business-as-Usual case, which assumes that the relevant parties in Mauritius continue to use (light) diesel-powered buses. Recall that the GHG mitigation case is incremental to the Baseline case.

[43] The emission factors used herein are taken from Salaway *et al* (1996), Friedrich *et al* (1998) and Faiz *et al* (1996).

The annual fuel cost of a diesel bus is about $4,000 (or about $3.5 million for the entire fleet). The useful operating life of an average bus in Mauritius is about 18 years (CSO, 1997).

5.5.3   *The GHG reduction inclusive Case*

This section presents a GHG reduction inclusive analysis at the project level, focusing on the "social" cost-effectiveness in abating carbon-weighted GHG emissions, and of substituting 880 LPG-powered buses for the 880 (light) diesel-powered fleet buses in Mauritius. A motor vehicle using LPG will not necessarily have low pollutant emissions, and this is especially true with respect to retrofitted existing vehicles (ETSU, 1997 and Green, 1996). Given this, we do not consider converting diesel buses to run on LPG, examining only direct original equipment manufactured (OEM) LPG-powered bus substitution.

The total change in GHG emissions, associated with substituting an OEM LPG-powered bus for a diesel-powered bus, expressed in terms of CO_2 equivalents, is calculated as follows:

$$\Delta \frac{\mathbf{t\, CO_2\, eq}}{\mathbf{bus \cdot year}} \cdot = \frac{\mathbf{km}}{\mathbf{bus \cdot year}} \times \left[GWP_{\mathbf{CO_2}} \times \Delta \frac{\mathbf{g\, CO_2}}{\mathbf{km}} + GWP_{\mathbf{CH_4}} \times \Delta \frac{\mathbf{g\, CH_4}}{\mathbf{km}} + GWP_{\mathbf{N_2O}} \times \Delta \frac{\mathbf{g\, N_2O}}{\mathbf{km}} \right] \times 10^{-6} \frac{\mathbf{t}}{\mathbf{g}}$$

where Δ denotes the "difference" in emission factors between a (light) diesel-powered bus and an equivalent OEM LPG-powered bus on the right hand side, and the estimated "change" in GHGs on the left hand side. The estimated annual change in GHG emissions (i.e. the GHG reduction inclusive benefit) is just over 2 t CO_2 eq. per bus. We assume that these savings accrue annually over the operating life of the OEM LPG-powered bus.

Based on a series of field trials ETSU (1997) estimated the total incremental capital cost (inclusive of refuelling infrastructure) of purchasing a new OEM LPG-powered bus, as opposed to a new diesel bus, at about $20,600 per vehicle[44]. The incremental annual recurring costs are computed for differences in fuel costs only; maintenance costs of both types of bus are assumed equal. The annual fuel cost per OEM LPG-powered bus is approximately $5,000, while the annual fuel cost of a diesel bus is around $4,000 (Markandya and Boyd, 1999). The (net) incremental recurring fuel cost is therefore $1,000 per bus per annum.

To estimate the total cost of replacing the four main operators' entire diesel-powered fleet, we assume that the existing buses will be replaced with OEM LPG-powered buses at current annual replacement rates, which over the period 1992 to 1996, averaged 87 new buses per year. Given this rate, it would take 10 years to replace the majority of the current diesel fleet with an OEM LPG fleet.

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[44]   The costs of the re-fuelling infrastructure could also have been built into the unit costs of the LPG, and <u>not</u> added to the incremental capital cost of the OEM LPG-powered bus.

5.5.3.1   Secondary (Collateral) Emission Savings

The proposed vehicle replacement programme will alter baseline emissions of CO, NO_x, PM_{10}, NMVOC and SO_2, and this case study also calculates the total change in annual emissions of these pollutants, resulting from the replacement programme, using unit damage costs (in terms of $ per tonne of pollutant) from Friedrich *et al* (1998a)[45].

5.5.3.2   Employment Effects

If a project creates a "new" job – i.e. employs a previously unemployed individual – this benefits society in the amount equal to the social cost of avoided unemployment. Therefore, the net social benefit of a "new" job created by the LPG-powered bus replacement programme is the product of two components: (1) the number of "new" jobs created by the project (and the period of employment); and (2) the social costs of unemployment[46].

We assume that the bus replacement programme will create employment through building the re-fuelling infrastructure. The estimated annual change in "new" employment in the construction/engineering sector is four full-time jobs, and the net social value of a "new" job in this sector is $10,500, making the total employment benefit associated with installing the required infrastructure just under $42,000 per year.   This "welfare gain" will accrue annually over the 10-year replacement programme period.

5.5.3.3   The "Social" Cost-Effectiveness of the LPG Bus Programme

We now evaluate the "social" cost-effectiveness (which we denote by FUCOSTEF) of the proposed OEM LPG-powered bus replacement programme, that is its effectiveness in reducing GHGs. We use the following cost-effectiveness[47]:

$$FUCOSTEF = \frac{\text{present value of the net incremental "social" cost stream}}{\text{present value of the carbon - weighted emission saving stream}}.$$

Table 5.11 shows estimates of FUCOSTEF for a combination of different discount rates. The "central" estimate, based on a discount rate of 10 percent applied to both the cost and emission savings streams, is about $600 per t CO_2 eq. abated (i.e. the PV GHG reduction inclusive costs are $5.1 mn and the PV GHG reduction inclusive benefits are 8,700 t CO_2 eq.).   If the cost analysis were based purely on private

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[45] The damage costs used are specific to the UK however, and two adjustments are needed prior to their application in Mauritius. The first adjustment is to reflect differences in income and hence, willingness-to-pay regarding the valuation of the health and environment damages. The second adjustment is to reflect (possible) differences in the magnitude of the physical damage per tonne of pollutant. See Markandya and Boyd (1999) for details of the adjustment process.

[46] **NB** that this does not amount to <u>double counting</u> the labour inputs to the project (see Chapter 3 for an explanation).

[47] The incremental "social" cost of the programme in any given year is equal to: the total annual incremental (investment and recurring) cost *less* the total annual incremental value of secondary emission savings *less* the total annual incremental cost of unemployment avoided.

(financial) costs, the programme's cost-effectiveness becomes $US 1,800 per tonne of CO_2 eq. abated. Under all credible estimates of the benefits of CO_2 this would be too high a cost.

5.5.4 Implications for Developing a Mitigation Strategy

Only one mitigation measure is considered in this case, but when several are considered, changing the evaluation criteria of the cost analysis results in a re-ranking of the set of measures comprising the least-cost abatement strategy[48]. In the transport sector, GHG mitigation measures will also yield additional social benefits – particularly, secondary emission savings.

Within a cost-benefit framework, the "central" estimate of FUCOSTEF is considerably higher than current estimates of climate change damages per tonne of CO_2 given in Delucchi (1998), implying that the net present value of the programme is negative, and therefore unjustifiable. Influencing the cost-effectiveness of this project is the price difference between diesel and LPG. For the "central case"(i.e. about $600 per t CO_2 eq. abated) :

If the retail price of diesel fuel increases or decreases by 20 per cent, the FUCOSTEF changes to $200 and $1,000 per tonne CO_2 eq. abated, respectively.
If the LPG fuel cost per kilometre were 6 or 15 cents (instead of 11 cents) the corresponding measures of FUCOSTEF are -$400 and $1,600 per tonne CO_2 eq. abated.

Clearly, a favourable fuel price differential – perhaps the result of taxing diesel or subsidizing LPG – improves the cost-effectiveness of this programme. However, something other than GHG abatement would be required to justify such a differential fuel tax.

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[48] See, for example, Markandya and Boyd (1999).

Table 5.11 Estimated "Social" Cost-Effectiveness of the Bus Replacement Programme

CO_2 equivalent reductions discounted at (PV GHG reduction inclusive benefits):

5 per cent	13.9	000' tonnes CO_2 equivalent
10 per cent	8.7	000' tonnes CO_2 equivalent
15 per cent	5.8	000' tonnes CO_2 equivalent

PV of total cost stream discounted at (PV GHG reduction inclusive costs):

5 per cent	3.8	$ million
10 per cent	5.1	$ million
15 per cent	5.3	$ million

FUCOSTEF with costs and GHG reductions discounted at

5 per cent; 15 per cent	660	$ per tonne CO_2 equivalent
10 per cent; 10 per cent	600	$ per tonne CO_2 equivalent
15 per cent; 5 per cent	400	$ per tonne CO_2 equivalent

Note: The shaded boxes identify the central case estimates.

5.6 Vehicle Maintenance Programme in Pakistan

5.6.1 Introduction

This GEF-supported project aims to reduce GHG emissions and other pollutants in Pakistan by improving the fuel efficiency of road transport vehicles (UNDP, 1996). The programme establishes engine tune-up demonstration and training centres – initially ten for gasoline and five for diesel vehicles – at various locations throughout Pakistan. These centres help develop service sector capabilities in the diagnosis of engine performance, and stimulate the market for these services. The programme establishes a revolving loan fund to finance service stations' purchasing vehicle tune-up equipment.

The total GEF-funding for the project is $US 7 million; the counterpart government input is Rs. 10.35 million (or about US $220,000). Approximately $US 3 million of the GEF-funding will be set aside for the revolving fund. The project was initiated in early 1997 and was proceeding as planned as of spring 1999.

5.6.2 Assessing the Project as a GHG reduction inclusive case

We assess the vehicle maintenance programme in two sections. First we quantify the GHG benefits of the programme, which are defined as the difference in total GHG emissions between a Baseline case and the GHG reduction inclusive case; both cases are defined below. Then we examine the incremental, or GHG reduction inclusive programme costs.

5.6.2.1 GHG Reduction Inclusive Policy Benefits

We estimate the GHG emissions reductions expected to result from the vehicle tune-up programme by following these steps:

1. Identify the types of vehicles the programme will affect.
2. Characterize the average annual emissions of each vehicle type <u>before</u> tune-up, defining the Business-as-Usual Case, which, in this case study, also represents the Baseline Case – there is no Transport Reform Case.
3. Calculate the average annual emissions of each vehicle type <u>after</u> tune-up. This defines the mitigation inclusive policy case.
4. Estimate the number of each type of vehicle the programme will affect.
5. Aggregate the data into Baseline (before tune-up) and Mitigation Inclusive (after tune-up) Case.

We discuss each of these steps below.

Step 1: Identify the types of vehicles the programme will affect

The motor vehicles fall into two categories: (1) gasoline vehicles, and (2) diesel vehicles. Within each of these categories, we further divide vehicles based on data in a 1991 transportation energy assessment of Islamabad (see Table 5.12).

Step 2: Characterize the Average Annual Emissions of each Vehicle Type <u>Before</u> Tune-Up

A survey conducted in the transportation energy assessment of Islamabad provides data for several vehicle types, on fuel consumption (tons per vehicle), distance travelled (km), and emission factor (gm/km). Consumption of gasoline and diesel fuel (as are SO_2 and lead) determines CO_2 emissions; the same emissions factor applies to all gasoline vehicle types (3.08 tonnes CO_2 per tonne of fuel) and all diesel vehicle types (3.08 tonnes CO_2 per tonne of fuel)[49].

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[49] CO_2 emissions per GJ are different for gasoline and diesel, but emissions per tonne of fuel are the same.

Table 5.12 Characteristics of Motor Vehicles Subject to Maintenance Programme

Vehicle type	Fuel type	Average distance (km/yr)	Average fuel use (t/yr)	NO_x emission factor (gm/km)	HC emission factor (gm/km)	CO emission factor (gm/km)	SPM emission factor (gm/km)
2/3 wheelers	Gasoline	12,000	0.25	0.20	4.50	30.00	3.50
Motor cars	Gasoline	15,000	1.10	1.10	3.80	34.00	2.10
Jeeps	Gasoline	15,000	1.83	1.10	3.80	34.00	2.10
Motor cabs/taxis	Gasoline	75,000	6.08	1.10	3.80	34.00	2.10
Delivery vans	Gasoline	20,000	1.46	1.10	3.80	34.00	2.10
Light pickups	Gasoline	45,000	3.29	1.10	3.80	34.00	2.10
Buses	Diesel	60,000	18.64	14.90	2.40	9.90	3.10
Trucks	Diesel	65,000	22.62	14.90	2.40	9.90	3.10
Station wagons	Diesel	75,000	8.16	14.90	2.40	9.90	3.10
Heavy pickups	Diesel	45,000	3.92	1.20	0.70	1.40	1.60
Jeeps	Diesel	15,000	1.31	1.20	0.70	1.10	1.60

Step 3: Calculate Average Annual Emissions for Each Vehicle Type <u>After</u> Tune-Up

The National Energy Conservation Center conducted a tune-up demonstration programme, producing estimates of improvement in fuel efficiency and subsequent reduction in emission factors for several vehicle types and models. Based on these, it was further estimated that tune-ups could result in the average emission reductions given in Table 5.13. To simplify the study, the same percentage reduction was applied to all vehicles using the same fuel.

Table 5.13 Estimated Emission Reductions Resulting from a Tune-Up

Vehicle type	CO_2	SO_2	Lead	NO_x	HC	CO	SPM
Gasoline	6%	6%	6%	6%	21%	45%	20%
Diesel	6%	6%	6%	6%	17%	8%	20%

Step 4: Estimate the Number of Each Type of Vehicle Affected by the Programme

Table 5.14 shows estimates for the number of vehicles expected to receive tune-ups over a five-year period, which were based on the number of tune-up stations expected to be in operation and the projected average number of tune-ups per day.

Table 5.14 Estimated Number of Vehicles Affected by Programme

	YEAR				
	1995-96	1996-97	1997-98	1998-99	1999-00
Number of operating stations:					
Gasoline	10	51	90	90	90
Diesel	5	15	25	25	25
Tune-ups conducted/day/station:					
Gasoline	12	15	20	20	20
Diesel	6	8	12	12	12
Number of vehicles serviced[1]					
Gasoline	18,000	114,750	270,000	270,000	270,000
Diesel	9,000	36,000	90,000	90,000	90,000

Notes:
[1] It was assumed that each gasoline vehicle would receive two tune-ups per year, and each diesel vehicle one per year.

Step 5: Aggregate Data into Baseline (before tune-up) and GO (after tune-up) Cases

The Baseline case estimates the fuel use and emissions, if the vehicles expected to receive tune-ups <u>do not</u> get such tune-ups. Thus, we calculate the annual total fuel use (F) for gasoline or diesel:

$$F = \sum AF_i * N_i .$$

Where:

AF_i = average annual fuel use for each vehicle type i, and
N_i = number of vehicles of each type i expected to receive tune-ups.

The total emissions (E) of CO_2 (and SO_2 and lead) in each year can be calculated as:

$$E = \sum AF_i * EF * N_i .$$

Where:

AF_i = average annual fuel use for each vehicle type i,
N_i = number of vehicles of each type i expected to receive tune-ups, and
EF = emissions factor for CO_2 (or SO_2 or lead).

The emissions (E) of other pollutants (NO_x, HC, CO, and SPM) in each year can be calculated as:

$$E = \sum D_i * N_i * EF_i .$$

Where:

D_i = average annual distance travelled for each vehicle type i,
N_i = number of vehicles of each type i expected to receive tune-ups, and
EF_i = emission factor for each vehicle type i.

The mitigation inclusive policy case estimates what the fuel use and emissions would be if the vehicles expected to receive tune-ups <u>do</u> get tune-ups. Thus, the annual fuel use (F) can be calculated as:

$$F = \sum AF_i * (1 - AR_i) * N_i .$$

Where:

AF_i = average annual fuel use for each vehicle type i,
AR_i = average reduction (in percent) in fuel use resulting from tune-ups, and
N_i = number of vehicles of each type i expected to receive tune-ups.

The emissions (E) of CO_2 (and SO_2 and lead) in each year can be calculated as:

$$E = \sum AF_i * (1 - AR_i) * EF_i * N_i .$$

Where:

AF_i = average annual fuel use for each vehicle type i,
AR_i = average reduction (in percent) in fuel use resulting from tune-ups,
EF_i = emission factor for each vehicle type i, and
N_i = number of vehicles of each type i expected to receive tune-ups.

The emissions (E) of other pollutants (NO_x, HC, CO, and SPM) in each year can be calculated as:

$$E = \sum D_i * EF_i * (1 - AR_i) * N_i .$$

Where:

> D_i = average annual distance travelled for each vehicle type i,
> EF_i = emission factor for each vehicle type i,
> AR_i = average reduction (in percent) in emissions factor resulting from tune-ups, and
> N_i = number of vehicles of each type i expected to receive tune-ups.

The difference in total fuel use and emissions between the Baseline case and the mitigation policy case – i.e. the global benefits of the project – are shown in Table 5.15 for 1996-97.

Table 5.15 Estimated Reduction in Fuel Use and Emissions Due to Project in 1996-97 (tonnes abated)

Vehicle type	Fuel Use	CO_2	SO_2	Lead	NO_x	HC	CO	SPM
Gasoline	12,929	39,820	52	7	187	3,872	63,998	2,488
Diesel	71,300	222,219	1,426	0	3,725	1,787	3,345	2,855
Total	84,229	262,040	1,478	7	3,912	5,659	67,343	5,342

5.6.2.2   GHG reduction inclusive programme costs

The GHG reduction inclusive costs of the programme are approximated herein using a simple "bottom-up" approach.

Before the programme is implemented – i.e. under the Baseline Case - a typical gasoline vehicle owner pays Rs. 55 per year for tune-ups. An instrumented tune-up under the programme however, is anticipated to cost Rs. 150. (It is assumed that this figure represents a "levelled price", in that it approximates the incremental annual investment and recurring costs incurred by the service station owner in providing the instrumented tune-up.) Given that owners of gasoline vehicles undertake two tune-ups per year, the annual incremental cost is Rs. 245 (i.e. Rs. 150 *x* 2 – Rs. 55).

At the same time, the instrumented tune-ups are expected to yield annual fuel consumption savings of 90 litres per vehicle. Given that the price of gasoline is Rs.14.3 per litre, gasoline vehicle operators will accrue fuel cost savings of about Rs. 1,290 per year. Hence, the net incremental annual cost (saving) of the programme for

operators of gasoline vehicles is negative Rs. 1,000 per vehicle. In 1996-97 it is estimated that 144,750 gasoline vehicles will be serviced under the new programme (see Table 5.). Hence, in 1996-97 total net incremental costs (savings) amount to some negative Rs. 119 million per year.

A similar analysis is required for a typical diesel vehicle owner. The net fuel cost saving accruing to diesel vehicle owners is about Rs. 5,830, while the incremental tune-up cost is Rs. 520. The higher fuel savings are brought about by an average diesel vehicle usage of 56,500 km per year, compared to only 15,000 km per year for a gasoline vehicle. The net incremental annual cost (saving) of the programme for operators of diesel vehicles is therefore negative Rs. 5,310 per vehicle. In 1996-97 it is estimated that 36,000 diesel vehicles will be serviced under the new programme (Table 5.14). Total net incremental costs (savings) in 1996-97 are thus negative Rs. 191 million per year.

Collectively, i.e. considering both categories of vehicles, the total net annual costs (savings) of the programme in 1996-97 amount to negative Rs. 310 million. In that year the programme is estimated to save about 262, 000 tonnes of CO_2 (Table 5.15). The cost-effectiveness of the programme in abating CO_2 emissions is therefore:

$$\frac{-\,\text{Rs.}\,310\,\text{million per year}}{262,000\,\text{tonnes}\,CO_2\,\text{per year}} = -\text{Rs.}\,1,200\,\text{per tonne}\,CO_2\,.$$

This equals a savings of about \$US 25 per tonne abated CO_2.

5.7 Summary

This chapter has demonstrated how GHG mitigation can be incorporated into transport policy at the local level. Programs to reduce local pollutants or improve travel efficiency have GHG implications and these can be estimated. Furthermore, the programs can be modified to generate greater reductions in emissions and these too can be estimated and their costs assessed. In the final analysis the modifications have to be evaluated in terms of the changes in local and global benefits and here a wide range of outcomes is possible.

6. Environmental Impacts of Transport

6.1 Introduction

This chapter presents an overview of the main environmental impacts of the transport sector. These impacts are reviewed to demonstrate the need for them to be recognised in the formulation of transport policy. In the terms of the conceptual framework presented in Chapter 2, this recognition is important as the analyst begins to explicitly incorporate environmental impacts into the appraisal process, e.g. by expressing the impacts in monetary units, and moves from an economic appraisal based on **private** costs to one based on **social** costs.

The chapter therefore identifies the human health and environmental effects of emissions from motor vehicles. The chapter first considers global air pollution problems – the enhanced greenhouse effect. The second part of the chapter is an overview of local and regional transport air pollutants. Transport activities are linked to a number of other impacts, in addition to those associated with air emissions – these other impacts are considered in section 6.3. Finally, the chapter concludes by briefly looking at the main issues relating to sustainability and the transport sector
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6.2 Air pollution from transport

6.2.1   Global Impacts

The main energy source warming the Earth is radiation from the sun. This takes the form of short-wave radiation because of the sun's high temperature and includes visible light and ultra-violet radiation. The Earth intercepts some of this radiation, which warms the surface, and is then re-emitted. Since the earth is much cooler than the sun, it emits terrestrial radiation at longer wavelengths, in the infrared part of the spectrum. The balance of this incoming radiation from the sun, and the outgoing infrared radiation from the Earth determines the temperature on the Earth.

The Earth's atmosphere is made up of gases, some of which absorb radiation of particular wavelengths. The main gases are nitrogen (78 percent) and oxygen (21 percent), neither of which emit or absorb terrestrial radiation. Water vapour, carbon dioxide, and a number of other **trace gases** absorb some of the terrestrial radiation leaving the Earth, and re-emit it back towards the Earth's surface as infrared heat radiation. These trace gases do not affect incoming solar radiation. This is the **natural greenhouse effect**, so-called because the trace gases act like the glass on a greenhouse, permitting the sun's rays to penetrate, but reflecting some of the outgoing terrestrial radiation back into the 'greenhouse', keeping it warm (Parry and Carter, 1998). In the absence of these **greenhouse gases** (GHGs), the average temperature at the surface of the Earth would be about – 19 ^{o}C, instead of + 15 ^{o}C (Ramanathan *et al*, 1987).

Various human activities result in the emission of GHGs, increasing their atmospheric concentrations. Atmospheric GHG increase has coincided with the industrialisation of society, which began in Europe, but has since spread globally.   Rising GHG concentrations enhance the natural greenhouse effect, such that more terrestrial

radiation is absorbed and re-emitted back to Earth. The result is a warming atmosphere near the surface of the Earth, known as the **enhanced greenhouse effect**, or just the greenhouse effect. The greenhouse effect leads to changes in climate patterns, and it is now thought that it could result in a higher global average temperature within the next century. Such a climate change would have serious consequences both for natural ecosystems, and human society. The impacts of climate change have been well documented by the Intergovernmental Panel on Climate Change (IPCC, 1996a, 2001a).

The main GHGs are **carbon dioxide** (CO_2), **methane** (CH_4) and **nitrous oxides** (N_2O). Others include carbon monoxide (CO), non-methane hydrocarbons (NMHC), and oxides of nitrogen (NO_x). The latter two groups of gases contribute to increasing concentrations of tropospheric ozone, which is an important GHG. Carbon monoxide, once emitted to the atmosphere, is oxidised to form CO_2.

A greenhouse gas's effectiveness in warming the atmosphere depends on both its concentration and on the amount of time it remains in the atmosphere. A GHG's contribution to global warming often is measured by its **global warming potential** (GWP), a ratio of the global warming effect from one kilogram of a GHG relative to the effect of one kilogram CO_2 over a specified period of time. The Intergovernmental Panel on Climate Change (IPCC, 1996b) for example, recommends using a GWP of 24.5 for CH_4, and 320 for N_2O, for a timeframe of 100 years[50]. There are professional and learned disagreements about how to measure GWP, and therefore about which figures to use. To estimate the combined (global warming potential) impact of all GHG emissions from a single source, one can convert all mass emissions of non-CO_2 greenhouse gases into an equivalent mass amount of CO_2 emissions, using the appropriate GWPs, and then calculate aggregate overall GHG emissions. The resulting aggregate GHG emission is expressed in terms of mass units of CO_2 equivalent.

Of the GHGs, CO_2 has contributed the most to atmospheric change. On a global scale, motor vehicles play a large role in the GHG emissions. According to IEA statistics, transport activity accounted for about 22% of world GHG emissions in 1995. By far the greatest contribution to transport sector GHG emissions is made by CO_2 – accounting for over 95% of the annual global warming potential produced by the sector (Price *et al*, 1998). Since the amount of CO_2 resulting from the combustion of a given quantity of gasoline or diesel remains constant regardless of emission controls, trends in CO_2 emissions will directly follow increases in the use of these fuels, and therefore, motor vehicles have the potential to play an even greater role in the enhanced greenhouse effect in the future.

The contribution of road transport to **nitrous oxide** (N_2O) emissions is small but significant. General Motors (GM) Research Laboratories has concluded that vehicular emissions of N_2O are about 200,000 tons world-wide, corresponding to about 3% of global N_2O emissions (GM, 1992). Nitrous oxide is formed, along with other oxides of nitrogen, during atmospheric combustion processes. Under normal atmospheric conditions, N_2O is rapidly oxidised to nitric oxide, which like N_2O is effectively non-

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[50] Of course, the GWP for CO_2 is 1 as this gas forms the base around which other gases are measured.

toxic to humans. However, unlike other oxides of nitrogen, N_2O is a greenhouse gas. N_2O emissions tend to increase with the use of three-way catalytic converters, and are up to four times higher under urban driving conditions. N_2O emissions from diesel trucks are also relatively high, exceeding the emission rate of three-way catalyst cars (GM, 1992). Emissions from older or malfunctioning vehicles are also higher than those from new, properly functioning, vehicles. Low temperatures and relatively high NO concentrations favour N_2O formation compared to CO, as do rhodium catalysts, which are more efficient in producing N_2O than platinum ones.

Methane (CH_4) is one of a group of substances collectively referred to as **hydrocarbons** (HC) – compounds consisting of carbon and hydrogen. Unlike other hydrocarbons however, CH_4 does not participate in chemical reactions in the troposphere. Hence, CH_4 does not play an important role in ozone formation and its associated environmental hazards (see below). Nonetheless, CH_4 is a key GHG with a direct radioactive forcing potential nearly 25 times that of CO_2. Road transport contributes 1% of methane emissions world-wide (OECD, 1995).

Other motor vehicle emissions, namely NO_x, NMHC and CO, are indirect contributors to global warming since they contribute to increasing **tropospheric ozone** (O_3), which is an important greenhouse gas[51]. Ozone in the free troposphere above the boundary layer (i.e. beyond 1,500 meters) is steadily increasing on a global scale. These background levels have doubled over the last century, and global monitoring programmes have revealed that long-term ozone concentrations are increasing by about two to three percent per year in the higher troposphere of the western hemisphere (Volz and Kley, 1988; Ciborowski, 1989). Concentrations of global tropospheric ozone are approaching levels at which environmental damage occurs, further contributing to global climate change.

Table 6.1 shows the impacts of various types of motor vehicles on global warming. The IPCC-provided ranges are, for the most part lower than the damages estimated as part of a preliminary evaluation of global warming damages by the ExternE project[52]. Estimates indicate that heavy goods vehicles are costlier in terms of damages from global warming than other transport types, and that diesel cars are less costly in terms of damages than their gasoline counterparts. Note that these damage cost differentials are solely a function of differences in average emissions and travel distances between the various vehicle types.

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[51] See, for example, OECD (1995) for an explanation of the mechanisms through which carbon monoxide can contribute to elevated concentrations of tropospheric ozone and methane.

[52] The differences between the IPCC damage estimates and those of ExternE can be explained in that the IPCC estimates exclude higher order damages like war and famine. If higher order effects are excluded from the ExternE analysis then similar ranges are obtained for damages (Friedrich, Bickel and Krewitt, 1998). Results from ExternE suggest that these effects may be considerable and that they should be included in the damage estimates. The IPCC estimates are also inconsistent with ExternE in the treatment of health valuation, but this is a minor issue compared to the impacts of war and famine.

Table 6.1 Global Warming Damages Due to Carbon Dioxide from Several Damage Factors

Vehicles	IPCC ranges			ExternE preliminary
	($5 / t C)		($125 / t C)	($170 / t C)
	(cents / p-km)		(cents / p-km)	(cents / p-km)
Gasoline car	0.013	-	0.485	0.668
Diesel car	0.013	-	0.380	0.511
Bus	0.008	-	0.249	0.341
Inter-city train	0.013	-	0.380	0.524
	(cents / t-km)		(cents / t-km)	(cents / t-km)
Heavy goods vehicle	0.013	-	0.563	0.773

Source: Friedrich, Bickel and Krewitt (1998)
Notes:
1. Estimates are based on emission factors for Germany.
2. ExternE preliminary results from the FUND Model, "base case" assumptions, and a 1 per cent discount rate.

To summarise, the transport sector is an important contributor to the greenhouse effect through the emission of greenhouse gases. Carbon dioxide, methane and nitrous oxides all have an impact on the level of radiation retained by the Earth and hence impact on the level of climate change expected. As a result, it is important that transport sector work include consideration of the impact on the global environment - the methodology for which is presented earlier in this book.

6.2.2 Regional and Local Impacts

6.2.2.1 Introduction

Motor vehicle-related air pollution is also an issue on the regional scale. The large-scale formation of photochemical oxidants from the precursor emissions NO_x and non-methane hydrocarbons (NMHC), together with secondarily formed acidic aerosols, damages vegetation, particularly forest ecosystems and some crops (OECD, 1995). These emissions also contribute to acid deposition, the main cause of which is the emission of sulphur and nitrogen compounds. Direct health risks to humans from motor vehicle emissions are most common in urban areas, local to the source, where large populations are exposed to high concentrations of pollutants. A study on urban air quality conducted the United Nations in 1988, found only 20% of the world's urban population live in cities with acceptable air quality. Pollutants from motor vehicles include carbon monoxide, lead, particulates, nitrogen dioxide and oxidants, all of which are present in cities in concentrations frequently exceeding international health standards (WHO, 1987). Of these pollutants, lead and fine particulates are a

concern during the early stages of motorization in developing countries, and subject to meteorological conditions, ozone can become a serious health problem.

6.2.2.2   Particulate matter

Particulate matter (PM), or simply particulates consist of a mixture of organic and inorganic substances, which may be in either liquid or solid form. They are categorised by size, with coarse particles defined as those having an aerodynamic diameter greater than 2.5 μm generally consisting of earth crustal materials and fugitive dust from roads; and fine particles, being less than 2.5 μm, and comprising secondarily formed aerosols, combustion particles, and re-condensed organic metallic vapours. The acid component of PM generally occurs as fine particles.

Particulate matter terminology includes: (1) that relating to measuring methods (i.e. total suspended particulates (TSP), black smoke (BS)); (2) site of deposition in humans (e.g. inhalable, thoracic particles); or (3) physical characteristics (e.g. PM_{10}, which refers to an aerodynamic diameter of less than 10 microns). We further distinguish between '**primary**' and '**secondary**' particulates, with the former emitted directly to the atmosphere while the latter form in reactions with other pollutants. In urban areas, most secondary particulate matter occurs as nitrates formed in reactions involving NO_x (Butterwick, *et al*, 1992). Secondary particulate matter also occurs as sulphates formed from SO_x.

Particulates are among the most harmful components of vehicle exhaust. Studies show a link between air borne particles and mortality, morbidity and deficits in pulmonary function[53]. Particulates also irritate the mucous membranes that line the respiratory tract, giving rise to breathing difficulties and feelings of discomfort. Certain constituents such as polyaromatic hydrocarbons, derived from the hydrocarbons in the fuel, also may be carcinogenic.

Other environmental effects of particulates include the soiling of exposed surfaces. The actual interactions between the surface of a building and particulates are complex, but carbon particles are known to act as a catalyst for reactions in which calcium carbonate (in the form of limestone, for example,) is converted to gypsum or calcium nitrate. Other impacts from particulates include the visibility impairment, potential modification of climate, and contribution to acid deposition (Butterwick, *et al*, 1992).

6.2.2.3   Volatile Organic Compounds (hydrocarbons)

The **volatile organic compounds** (VOCs) comprise a wide range of individual substances of sufficient volatility to exist as vapour in the atmosphere. VOCs associated with transport include: **hydrocarbons** (HC)[54] and their derivatives, which are formed during combustion; those associated with the evaporation of fuel; and halogenated compounds used in manufacture and maintenance of vehicles and

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[53] See, for example, Working Group on Public Health and Fossil Fuel Consumption (1997); Pope *et al* (1995); and Dockery and Pope (1993).

[54] Hydrocarbons, as stated above, are organic compounds consisting primarily of hydrogen and carbon.

aircraft. If transport-related emissions from oil refining and distribution are taken into account, transport is the most important source of anthropogenic VOC, at least in OECD countries (OECD, 1995).

The effects of VOCs on human health are compound-specific. Some are significantly toxic. Generally, the intestines and lungs absorb VOCs, and their breakdown in the body can give rise to carcinogenic metabolites. In addition, many hydrocarbons are themselves suspected or known carcinogens. Hydrocarbons and nitrogen dioxide are also associated with the formation of photochemical smog, which can cause respiratory problems. Other VOCs are toxic in their own right, for example **benzene**, **PAH**, and **formaldehyde**. Certain alternative fuels, such as methanol or ethanol produce more aldehydes than are associated with the combustion of gasoline.

There is little quantitative data on the effects of exposure to VOCs in exhaust emissions, and the extent to which individual VOCs of exhaust contribute to health effects is not known, but both hydrocarbons and aldehydes are known to cause irritation of the skin and mucous membranes, and both lead to breathing difficulties. Long-term exposure to hydrocarbons has been shown to impair lung functions. The VOC benzene is absorbed by the body after inhalation, and is stored in bone marrow and fat, and is known to have carcinogenic effects. Toxicologically, benzene affects the central nervous system as well as the blood and immune system, with specific carcinogenic effects including leukemia (Onursal and Gautam, 1997). Many VOCs contribute to secondary pollutant formation and to stratospheric ozone depletion. They also contribute indirectly to the formation of atmospheric acidity.

6.2.2.4   Carbon Monoxide

Carbon monoxide (CO) is a colourless, odourless, tasteless gas, which is slightly lighter than air. It is a product of incomplete combustion of carbonaceous fuels in motor vehicles, and therefore is produced in greater quantities when engines run inefficiently. Motor vehicles, especially cars, are the main contributors to anthropogenic CO emissions worldwide (Onursal and Gautam, 1997). Under normal atmospheric conditions, CO reacts with hydroxyl radicals and is converted to CO_2. Where there are high concentrations of CO however, local depletion of hydroxyl radicals can lead to a build-up of CO and CO_2, both of which are GHGs.

Carbon monoxide is toxic to vertebrates, combining with haemoglobin in the blood to form the stable complex carboxyhaemoglobin, which reduces the blood's capacity to carry oxygen. High CO concentrations can cause loss of consciousness and death, while lower concentrations affect nervous system functions and can result in impaired vision, learning disability, slow reflexes, decreased manual dexterity and mental functions, headaches and drowsiness. Individuals most at risk to the effects of CO are those with existing cardiovascular or chronic respiratory problems, the elderly, young children and foetuses. Plants produce and metabolise CO, and are only harmed by prolonged exposure to very high levels. CO may be toxic to some invertebrates.

6.2.2.5   Oxides of Nitrogen

"Nitrogen oxides" (NO_x) is a collective term that refers to two species of oxides of nitrogen, nitric oxide (NO) and nitrogen dioxide (NO_2). These two oxides are grouped

together because most anthropogenic NO_2 derives from NO emissions. Because this transformation occurs rapidly, NO_2 generally is regarded as more important in terms of human health. Motor vehicles are the main anthropogenic source of nitrogen oxide resulting from high temperature nitrogen combustion in vehicle engines (Onursal and Gautam, 1997), and emissions from vehicles with catalytic converters are an order of magnitude higher than those from cars without catalytic converters.

A variety of respiratory system ill effects have been linked to short- and long-term exposure to NO_2. These include altered lung function, increased prevalence of acute respiratory illness and lung tissue damage, and increased susceptibility to infection. Lung function, for example, is affected by 30-minute exposure to a NO_2 level of 560 $\mu g/m^3$ with exercise, 940 $\mu g/m^3$ in asthmatics, and above 1,300 $\mu g/m^3$ in healthy individuals (Onursal and Gautam, 1997). Certain human health effects may occur because of exposures to, or approaching recorded ambient concentrations of NO_2 – annual mean concentrations in urban areas are generally in the range of 20 to 90 $\mu g/m^3$, although concentrations can vary significantly throughout the day (Butterwick, *et al*, 1992). Young children and asthmatics are the groups at greatest risk from ambient NO_2 exposures.

Nitrogen dioxide also affects the natural environment, with high concentrations retarding growth and causing visible damage to plants. Lower concentrations however, promote plant growth, particularly where soil is nitrogen deficient. Nitrogen oxides are involved in reactions that produce nitrous and nitric acid, which can be deposited from the atmosphere by means of dry or wet deposition. Effects of this are soil and aquatic ecosystems acidification, and eutrophication of freshwater, soil and marine environments.

6.2.2.6   Sulphur Dioxide

Sulphur dioxide (SO_2) is a colourless gas that reacts on the surface of a variety of airborne solid particles, is water soluble, and can be oxidised within airborne water droplets.

SO_2's contribution to vehicle emissions is relatively small compared to power station and refinery contributions. The World Bank estimates that the transport sector's contribution to global SO_2 emissions is between two and six percent. However, vehicle emissions can be significant in particular locations, for example where traffic is congested, or in harbour areas. Diesel fuelled vehicles emit the highest SO_2 levels, although they are likely to decline as diesel fuel sulphur level decrease.

Certain concentrations of SO_2 give rise to respiratory problems such as aggravation of bronchitis and asthma. At very high levels, and combined with suspended particles, SO_2 can be responsible for high mortality levels. Sulphuric acid and other sulphates also have adverse human respiratory effects. Evidence exists that low levels of SO2 negatively affect some species of plants, particularly trees, though measurement of such impacts is complicated by other pollutants.

6.2.2.7   Lead

Two of the most important compounds of **lead** in the context of air pollution are tetraethyl and tetramethyl lead, both of which are used extensively as 'anti-knock' additives in gasoline. Motor vehicles fuelled with leaded gasoline are the major source of atmospheric lead. Increasing availability of lead-free fuel and controlled levels of lead in fuels has resulted in a diminished contribution from this source. In addition, leaded gasoline cannot be used in cars that are fitted with catalytic converters.

Lead is a cumulative poison. Most airborne lead is in fine particle form, inhaled and deposited in the lungs or absorbed by the intestines. Children have higher absorption rates than adults, and poor diet enhances absorption rates. Lead accumulates in the liver, kidneys, brain, bone and nervous tissue. Long-term exposure to high doses can affect many organ systems, the most serious being on the nervous system, haemoglobin synthesis and haemopoiesis.

Studies into the effects of low-level exposure in children are inconclusive, although there are links between blood lead and IQ, and between blood lead and foetal growth. Also, lead is generally toxic to both flora and fauna although at current environmental levels no serious effects have been recorded.

6.2.2.8   Ozone

Ozone (O_3) is the tri-atomic form of molecular oxygen. It is one of the strongest oxidising agents, and is highly reactive. In the lower atmosphere, O_3 is formed by sunlight on nitrogen oxides, thus motor vehicle emissions are the main anthropogenic source of O_3 precursors.

Ozone and other oxidants cause a range of acute effects, including eye, nose and throat irritation, chest discomfort, coughs and headaches. At certain concentrations, O_3 is linked to pulmonary function decrements in children and young adults.

Other environmental effects of O_3 include damage to materials and vegetation. Studies show that high levels of O3 cause visible damage to some plant species, and reduce growth in some crops. Evidence suggests that present O_3 levels (in the UK) affects crop yields at least in some years, and may be affecting natural vegetation in the same way it affect crops, potentially affecting the natural vegetation's species composition. Table 6.2 summarises the main air emissions from transport, their main sources and, where appropriate, their direct impact on human health, and whether they are associated with local, regional and/or global impacts.

Table 6.2 Air Pollution from Motor Vehicles: Summary of Impacts

Pollutant	Type of impact						Source of pollutant	Health effect of pollutant
	Local	Regional		Global				
	High Concentrations	Acidification	Photo-chemical Oxidants	Indirect GHG	Direct GHG	Stratospheric Ozone Depletion		
Particulate matter	X		X				Products of incomplete combustion of fuel; also from wear of brakes and tyres	Irritates mucous membranes; respiratory / pulmonary effects; carcinogenic
Lead	X						Added to gasoline to enhance engine performance	Acute circulatory, reproductive, and nervous systems
Carbon monoxide	X		X	X			Incomplete combustion product of carbon-based fuels	Reduced oxygen carrying capacity of red blood cells
Nitrogen oxides	X	X	X	X		X	Formed during fuel combustion at high temperatures	Irritated lungs; increases susceptibility to viruses
Sulphur dioxide	X	X					Combustion of petroleum products	Reduced lung function / impairment of respiratory system
Volatile organic compounds	X		X	X			Combustion of petroleum products; also evaporation of unburned fuel	Irritated eyes, causes intoxication; carcinogenic
Tropospheric ozone		X	X	X			Not an exhaust gas; product of photochemical reaction of NO_x and VOCs in sunlight	Irritates mucous membranes of respiratory system; impairs immunities
Carbon dioxide					X		Combustion product of carbon based fuels	
Methane					X		Leakage during production, transport, filling and use of natural gas	
Nitrous oxide				X	X	X	Combustion product of fuel and biomass, also formed in catalytic converters	

Source: OECD (1997)

6.3 Other Transportation System Impacts

6.3.1 Introduction

In addition to the impacts of vehicle emissions identified above, the transport sector can be linked to a number of additional impacts. These "other" impacts, reviewed below, include noise, vibration, ecological damage, resource use, congestion, and accidents.

6.3.2 Overview of "Other" Transport Impacts

Transport has been identified as the main cause of environmental **noise** (OECD, 1997). Noise impacts can be divided into auditory effects and non-auditory effects. With respect to motor vehicles, auditory effects relate to interference with communication and cognitive processes.   Non-auditory effects of noise include disturbed sleep, cardiovascular and psychoendocrine effects, clinical health effects, community annoyance and behavioural effects.

Vibration is caused almost exclusively by heavy vehicles, in turn causing nuisance comparable to noise, but vibration also has harmful effects on soil, infrastructure, buildings and underground services. These effects range from cracks to structural damage.

Construction of the transport infrastructure uses potentially significant areas of land, disrupting, fragmenting or destroying habitats, and severing migration routes, thereby affecting **biodiversity**. Trees may become more sensitive to wind, frost, damage by pests etc., due to atmospheric pollutants. The construction of transport infrastructure also affects both surface and underground **watercourses**, most significantly relating to disruption of drainage systems, increased run-off, and reduced infiltration rates. Vehicular transportation does not directly cause high levels of water pollution, although oil and hazardous materials can leak from vehicles, particularly in the event of an accident. Accidents potentially may contaminate groundwater, which may be a source of drinking water.

Loss of agricultural land due to construction projects creates its own problems, for example fragmentation of farmland, reduced food production levels, etc. Surrounding land continues to be affected after construction, by maintenance activities.

Transport-related construction projects require considerable amounts of rock, gravel and soil. Each kilometre of a four-lane highway requires about 46,000 m^3 of coarse aggregate and gravel (CEC, 1996). Extraction of these materials has had a significant local impact, both visual and ecological, and can itself affect watercourses and drainage. Large construction projects also have an impact on landscape structure and visual amenity. Visibility of traffic infrastructure construction will be greatest in open landscapes. Table 6.3 shows some of the infrastructure-related impacts.

Fossil fuel consumption is the greatest concern regarding transportation **resource use**. This concern is not just over emissions resulting from fuel combustion, but also over non-renewable resource depletion. Resource use relating to motor vehicle

manufacturing is also considerable, while increased use of electronic and plastic components makes vehicle recycling more difficult.

Table 6.3 Impacts of Transport Infrastructure

Impacts on:	Spatial dimension	Temporal dimension
Biodiversity	Local, regional and global	Irreversible
Geology, soils and water	Local (for water, sometimes regional)	Medium and long term/irreversible
Landscape	Local	Long term/occasionally reversible to a degree
Cultural heritage	Local, regional or global	Irreversible

Source: CEC (1996)

Road systems are also potentially associated with **congestion**. This exacerbates all vehicle emission impacts as it causes vehicles to operate at sub-optimal speeds and reduces engine efficiency [55]. In addition, congestion has considerable economic and social impacts, increasing the time required to travel a given distance, which in turn decreases time available for other activities (time has an opportunity cost). Finally, any transport system, particularly one associated with motor vehicles, will inevitably experience **accidents**. Transport users are the most likely to be affected, although those pedestrians and others in the vicinity may also be affected.

6.3.3 Damage Cost Estimates

Air pollution imposes serious costs on society, primarily health-related. Many air pollutants discussed above cause various forms of illness (**morbidity**), while others, primarily particulates, are linked to premature death (**mortality**). Air pollution is also responsible for (physical) damage to man-made and natural environments, including damage to ecosystems that support humans' livelihood, damage to physical infrastructure, and "soiling" facades and other physical material (Shah *et al*, 1997).

To include air pollution-related damages in the decision-making process, thereby improving social resource allocation, much effort has gone into placing monetary values on these damages. (For example, CEC, 1995 and 1998; Friedrich *et al*, 1998; Shah *et al*, 1997; and Wijetilleke and Karunaratne, 1995). Assessing air pollution damages to human health and to the natural environment is complex and controversial, but some basic estimates of transport air pollution-related damages are presented in Table 6.4 and Table 6.5[56]. The reductions in local air pollutants secondary to GHG mitigation policy may be seen as a secondary or ancillary benefit to such a policy[57] (see section 3.2.6.1).

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[55] For example emissions during stop-start are typically larger than during standard vehicle operation, for this reason they tend to treated separately when constructing emissions inventories.

[56] Physical impact and damage cost data from World Bank projects are provided in Ostro (1994), Ostro, Sanchez, Aranda and Eskeland (1995), and Brandon and Hommann (1995). Delucchi (1998) provides a overview of global warming damage costs.

[57] Krupnick et al (2000) present a conceptual framework for the inclusion of such secondary benefits in the context of climate mitigation analysis.

6.4 Sustainability Issues

6.4.1 Background

The issue of sustainability arises here because environmentalists are concerned that policies contribute to the long-term resolution of conflicts between protecting the natural environment and economic development. This issue, first brought into the public domain in a significant way by the Brundtland Report (World Commission on Environment and Development, 1987), was introduced as a search for a development path that meets the needs of present generations without compromising future generations' ability to meet their needs. Subsequently, concepts of 'weak' and 'strong' sustainability (Pearce, 1993) have entered the debate.

Weak sustainability pertains to the fact that society should develop its resources to ensure the passing on of a stock of wealth (including natural capital) to future generations at least as great as the one inherited by present generations. This stock is measured in monetary terms.

Strong sustainability considers the need to ensure that critical parts of the natural capital are not degraded, and that renewable resources are used in as sustainable a manner as possible, given economic development and constraints on resource use.

The appeal of weak sustainability is that it allows a degree of substitution between natural and man-made capital in the production process. There are significant differences of opinion about these notions among environmentalists and economists however.

Table 6.4 Damage estimates (vehicle use only) for diesel passenger cars in different locations ("best" estimates)

Diesel car	Agglomerations		Urban areas		Motorway driving	
	Paris (F)	Stuttgart (D)	Amsterdam (NL)	Barnsley (UK)	Stutt.-Mannheim (D)	Tiel Drive (NL)
	(cents / v-km)	(cents / v-km)	(cents / v-km)	(cents / v-km)	(cents / v-km)	(cents / v-km)
Primary pollutants:						
Particles (PM $_{2.5}$)	69.966	6.606	10.297	12.759	2.459	3.865
SO_2	0.122	0.147	0.093	0.105	0.079	0.042
CO	0.003	>0.001	>0.001	0.001	>0.001	>0.001
Toxic VOCs (Cancers)	0.527	0.071	0.075	0.164	0.024	0.029
Secondary pollutants:						
Sulphates	0.077	0.107	0.170	0.083	0.089	0.144
Nitrates	2.382	1.197	0.354	0.369	0.948	0.498
Ozone	0.169	0.126	0.118	0.122	0.102	0.157
Global warming	0.389	0.299	0.354	0.452	0.261	0.301
TOTAL	73.635	8.553	11.461	14.055	3.962	5.036

Source: Friedrich, Bickel and Krewitt (1998)

Notes:
1. Agglomerations (areas of highest population density over a large area) – 10 million people on a 50 x 50 km^2.
2. Urban areas (high population density over a large area) – 2 million people on a 50 x 50 km^2.
3. Motorway (extra-urban areas) – medium to low population densities.

Table 6.5 Damage Estimates (vehicle use only) for "Three-way-catalyst" Passenger Cars in Different Locations ("best" estimates)

Diesel Car	Agglomerations		Urban areas		Motorway driving	
	Paris (F)	Stuttgart (D)	Amsterdam (NL)	Barnsley (UK)	Stutt.-Mannheim (D)	Tiel Drive (NL)
	(cents / v-km)	(cents / v-km)	(cents / v-km)	(cents / v-km)	(cents / v-km)	(cents / v-km)
Primary pollutants:						
Particles (PM $_{2.5}$)	6.997	0.489	0.257	0.546	0.144	0.097
SO_2	0.138	0.016	0.013	0.043	0.008	0.009
CO	0.008	0.003	0.003	0.003	0.001	>0.001
Toxic VOC (Cancers)	0.043	0.024	0.008	0.100	0.004	0.008
Secondary pollutants:						
Sulphates	0.086	0.012	0.028	0.034	0.009	0.029
Nitrates	2.114	0.600	0.210	0.362	0.772	0.339
Ozone	0.162	0.071	0.067	0.186	0.084	0.109
Global warming	0.469	0.390	0.419	0.456	0.312	0.326
TOTAL	10.017	1.605	1.005	1.730	1.334	0.917

Source: Friedrich, Bickel and Krewitt (1998)

Notes:
1. Agglomerations (areas of highest population density over a large area) – 10 million people on a 50 x 50 km^2.
2. Urban areas (high population density over a large area) – 2 million people on a 50 x 50 km^2.
3. Motorway (extra-urban areas) – medium to low population densities.
4. Population density around the a road was found to be a key determinant of the magnitude of impacts, particularly for diesel vehicles.
5. The main source of difference between the case study results is differing emission factors.
6. The quantified damages are dominated by mortality impacts, in particular by damages due to particles. Mortality impacts are valued using the value of a life year lost approach (VLYL), based on the quantification of the number of years of life lost (YOLL) due to mortality.

6.4.2   GHG Projects Sustainability Indicators

In the context of GHG mitigation projects, notions of weak sustainability are to a large extent incorporated into the analysis developed in the previous sections. It is the strong sustainability notion that must be addressed here. Many policy-makers are concerned that programmes and policies introduced by donor agencies do not consider the implications of their proposals' natural resource indicators in terms of sustainability. Consequently, in developing policies for this area, objectives of sustainable resource use and protection of critical natural capital should be assigned some weight. Greater importance should be attributed to overall long-term policy implications in general. Table 6.6 gives a list of the critical indicators that should be provided for selected policy interventions in the transport field, in addition to standard economic measures of performance. A key indicator of sustainability in Table 6.6 is the project's impact on the share of total energy coming from renewable sources at the beginning and end of the planning period. This applies to almost all projects likely to be considered, and could be reported for **all** interventions, even those that will not affect renewable resource use.

Table 6.6 Sustainability Indicators for GHG Limitation Projects

Policy intervention	Sustainability indicators		
	Sustainable use of renewable resources	Key natural capital	Other
Switches in fossil energy use	Period for which new regime of fossil fuel use will be economically feasible.		Real cost/unit of energy from renewable energy source over the period.
Renewable energy/ Energy Conservation	Change in share of total energy from renewable sources at beginning and at end of planning period	Any impacts on key biodiversity or other natural assets of developing renewable sources	
Construction of roads or other transport delivery systems	Change in share of total energy from renewable sources at beginning and at end of planning period	Any impacts on key biodiversity or other natural assets	Impact of policies on share of total land for urban/suburban use.

Regarding fossil fuel policies, project time horizon is an important physical and economic consideration. At some point the fossil energy source may be so depleted that extraction costs will rise above renewable resource costs. For this reason the analyst should develop a clear view of expected trends in the real prices of alternative fuels. These should be reported in the sustainability indicators within the appraisal process.

Transport policies rarely affect the resource base directly, but some cases exist (e.g. alcohol programmes in Brazil). Such projects should assess the impacts on key forms of natural capital. This information probably will be a qualitative description of expected impacts. In some cases however, it is possible that quantitative data on

affected species or increased eco-system stress may be available. (For a further discussion see Mayerhofer (1997) and Rennings and Hoymeyer (1997).)

Finally, some transport projects will affect urbanisation and hence land used for agriculture. One sustainability-related concern is that land use trends are not sustainable; that is, as more and more land is taken into urban and suburban use, a loss of amenity and biodiversity will occur. A proxy for that is the change in the percentage of urban/suburban land.

6.5 Summary

The transport sector has a wide number of different impacts on the level of environmental quality. As the focus of this book suggests there are global consequences of transport sector expansion, in the form of an enhanced greenhouse effect, from increased transport activity. In addition, local air pollutants such as particulate matter, nitrous oxides and ozone, amongst others, may have a negative impact on human health, biodiversity and amenity values. Reducing levels of such pollutants might not be a primary objective of a GHG mitigation inclusive transport strategy. However, reductions in these pollutants may give secondary or ancillary benefits in terms of reduced levels of emissions and the consequential reduction in health, biodiversity and amenity impacts of the transport sector. Methodologies for the inclusion of such impacts in project analysis exist, including some monetary estimates.

The transport sector has other impacts than those brought by increased emissions. The impact of noise on health has been documented in the literature, and should be considered when constructing new roads. Vibration caused by heavy vehicles may have negative impacts on infrastructure and buildings. Construction of new roads may impact on biodiversity and watercourses, whilst accidents may contaminate drinking water sources through leaks of oil and hazardous materials.

Transport sector policies and projects should also be assessed as to its' impacts on sustainable use of resources and protection of critical natural capital. A key indicator of a project's impact on sustainability is its' impact on the share of total energy coming from renewables and the stock of natural capital at the beginning and end of the planning period. Sustainability impacts may also be felt in terms of increased urbanisation and the extent to which land is used for agriculture.

This chapter has identified the key impacts of the transport sector on the environment and sustainability concerns. These should be included as part of project analysis in transport sector work. The following chapter examines technical options for such work.

7. Technological and planning options

7.1 Introduction

This chapter presents the main mitigation technologies and supply- and demand-side planning options available for greenhouse gas emissions control. It reviews technical measures involving fuels and vehicles, transportation system management measures, infrastructure improvements, and land-use planning approaches, and assesses possibilities for introducing low-GHG-emitting fuels and state of the art technology options for improving vehicle energy efficiency. Other policy options exist, including economic instruments which are discussed in Chapter 8.

This chapter provides information on the technical characteristics, efficiency, cost and possible effects on transportation energy consumption and GHG emissions for each option. Wherever possible we provide examples of real world implementation and links to conventional transportation goals. We suggest ways in which GHG emission reduction initiatives might become part of a broader transportation agenda. Finally, we discuss each option's applicability to the developing country context.

The material in this chapter is informed by the literature available on technological and planning options, much of which is derived from sources in industrialised countries. Wherever sources are available to substantiate technology and fuel characteristics in developing countries, these are documented.

7.2 Alternative Fuel Options for Reducing GHG Emissions

Reliance on petroleum products such as gasoline or diesel is responsible for GHG emissions from transport. Switching to alternative fuels, particularly to less carbon-intensive fossil fuels or to non-petroleum based fuels, could significantly reduce overall GHG emissions due to their lower emissions per unit of service (vehicle-kilometre travelled or ton-kilometre of freight lifted). Given currently available technological options, use of alternative fuels in heavy-duty vehicles does not appear to offer significant GHG emission reduction benefits. Therefore, we treat fuel use of heavy-duty vehicles separately.

Road vehicle ownership and usage is increasing rapidly in the developing world. Road vehicle fleet expansion is particularly striking in China and India where, until recently, road vehicle transport played a relatively small role in the transport sector as a whole (EES, 1990). While this section focuses on road vehicles, fuel switching is a mitigation option for railways too, where switching from coal to diesel or to electric locomotives could reduce railway-related GHG emissions.

In addition to reducing GHG emissions, switching to alternative fuels reduces local air pollution substantially. Road vehicles are an important source of local air pollution in cities in the developing world, alongside industry. In Indian cities, gasoline fuelled vehicles, mainly two- and three-wheelers, account for about 85 percent of carbon monoxide emissions and 35-65% of hydrocarbon emissions. Diesel vehicles, mostly buses and trucks, emit roughly 90 percent of nitrogen oxide in Indian cities (EES,

1990). The synergy between greenhouse gas and local air pollutant reductions due to alternative fuel usage is discussed in Chapter 5.

7.2.1   An overview of systems and fuels

Alternative fuels and systems that use them comprise three types: internal combustion engine technologies; electric vehicle technologies; and hybrids. Alternative fuels for internal combustion engines include methanol (from biomass, natural gas or coal) ethanol (from biomass), compressed natural gas, liquefied petroleum gas, and hydrogen. Electric vehicles are powered either by batteries or fuel cells. Hybrid vehicles combine an internal combustion engine and an electric power system that is most often battery-powered. Other technical options for using alternative fuels include flexible fuel vehicles that run on ethanol, methanol, gasoline or any mixture of these, and bi-fuel vehicles with parallel fuel systems between which the operator can switch, such as compressed natural gas and gasoline. We outline this typology in Table 7.1.

Table 7.1 A Typology of systems and fuel options

System	Alternative fuel options (primary energy source in parentheses)
Internal combustion engine	Diesel (oil) Compressed Natural Gas—CNG (natural gas) Liquefied Petroleum Gases—LPG Methanol (from coal, natural gas, or wood), Ethanol (from corn, sugar cane, or wood), Hydrogen (various possible primary energy sources for the electricity used to make hydrogen). Modified internal combustion engine systems currently in production include (1) flexible fuel internal combustion engine systems that can burn ethanol, methanol, gasoline, or any mixture of these, and (2) bi-fuel vehicles that can switch back and forth between fuels, such as gasoline and natural gas.
Electric: Battery or fuel cell	Battery systems: Electricity (can come from many possible sources; currently most likely scenario is charging off local grid) Fuel cell systems: Hydrogen (feedstock can be gasoline, natural gas, or electricity derived renewable sources like ethanol or solar power)
Hybrid	A combination of electric battery and internal combustion engine systems with options described above.

7.2.2   *Alternative Fuels: Environmental and Economic Impacts*

Analysing GHG emissions requires us to perform a life-cycle analysis, which is an analysis of effects over the entire fuel cycle. Both GHGs and local pollutants are released into the atmosphere during vehicle use. They are also released in upstream fuel supplying activities. Stages in the fuel supply cycle are: extraction, transportation of the primary energy source, processing and refining, and refined product transport. In the case of electricity, additional transportation and conversion stages (for example, transportation of a refined product to an electrical power plant) are followed by electricity transmission and distribution.

Alternative fuel usage can reduce emissions from vehicle exhaust pipes while emitting more pollution during the rest of the energy supply cycle than during the conventional gasoline fuel cycle. If this increase away from the vehicle exhaust is large enough, a fuel switch project could cause a net increase in GHG emissions over the entire fuel cycle. For example, methanol or electricity produced from coal produces in greater life-cycle GHG emissions than conventional gasoline on an equalised basis.

Increased cost is often the trade-off in assessing the emissions benefits of alternative fuel systems emissions benefits. Vehicles using alternative fuels have higher initial costs than conventional vehicles. In some cases, lower fuel costs over the life of the vehicle offset these larger initial costs. Lifecycle costs vary by country, based largely on fuel prices. Other factors include vehicle availability and cost, and the need for associated infrastructure investment to support the implementation of alternative fuel vehicles. Research and development of infrastructure to support emerging technologies has typically lagged behind the technologies themselves.

Table 7.2 details the economic and environmental characteristics of alternative fuels in comparison to gasoline, and is based on IPCC (1996b). The following discussion is organised according to the potential for implementation of the fuels in question.[58] Currently implemented fuel options are discussed first, before more longer-term solutions are considered. Three categories are identified:

1. **Currently used fuels:** alternative fuels that are used in niche markets (ethanol, methanol, CNG, and LPG)
2. **Fuels ready to enter the market in the short term**, perhaps in under 5 years (hybrid vehicles)
3. **Fuels showing promise in the medium to long term**: including electric vehicles—fuel cell or battery powered vehicles and the potential use of hydrogen in internal combustion engines.

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[58]   It should be noted that this assessment of future potential necessarily implies some likely scenario of technological and market change. Such projections are inherently uncertain.

*Table 7.2. **Lifecycle GHG and economic impacts of fuel options**[a]*

GHG emissions in g/km CO_2-equivalent[b]					Costs (pre-tax)[c]			
Fuel	**Vehicle manufacture[d]**	**Fuel supply[e]**	**Operation[f]**	**Total**	**Vehicle cost (US$)**	**Fuel Cost ($/L gasoline equivalent)**	**Fuel use for cost calculation (L/100km)**	**Cost in excess of gasoline vehicle 29 US cents/km (US cents/km)**
Fuels for internal combustion engines								
Gasoline	25-27	15-48	182-207	222-282	15168	0.26	7.6	0
Reformulated Gasoline	25-27	17-63	180-193	222-283	15168	0.28-0.30	7.6	0.18 to 0.32
Diesel	27-29	7-35	139-202	173-266	15168-17443	0.26	6.08	-0.35 to 3.64
LPG	26-28	7-20	147-155	180-203	15384-16083	0.19-0.26	7.27	-0.55 to 1.02
CNG	29-31	5-68	130-154	164-523	15600-16083	0.18-.024	7.27	-0.28 to 0.90
Methanol from Coal	25-27	250	149	424-426	15168-16128	0.25-0.35	7	-0.72 to 1.45
Methanol from NG	25-27	76	149	250-252	15168-16128	0.25-0.25	7	-0.72 to 1.45
Methanol from Wood	25-27	25-38	15-16	65-81	15168-16128	0.68-0.82	7	2.30 to 4.79
Ethanol from Sugar Cane	25-27	30-80	15-16	70-123	15168-16128	0.35-0.38	7	-0.17 to 1.89
Ethanol from Corn	25-27	50-220	15-16	90-263	15168-16128	0.94-1.03	7	4.61 to 6.74
Ethanol from Wood	25-27	25-38	15-16	65-81	15168-16128	0.68-0.82	7	2.79 to 5.27
Liquid Hydrogen	26-28	0-48	3-12	29-88	18048-19968	0.38-1.44	6.5	4.10 to 13.97
Electric vehicles using electricity generated from: [g]								
American average	44-48	135-202	0	179-250				
European average	44-48	107-160	0	151-208	24768-20928		2-3	6.81 to 14.74
Coal	44-48	180-375	0	224-423				
Oil	44-48	170-255	0	214-303				
Gas (CCGT)	44-48	90-134	0	134-182				
Nuclear	44-48	15	0	59-63				
Hydro/Renewables	44-48	0	0	44-48				
Fuel Cell Electric Vehicle	44-48	0-24	0-5	48-77	20324-30000	0.38-1.44	3.25	6.22 to 25.64

[a] Source: based on IPCC (1996a)
[b] Based on an average driving cycle whereby a gasoline car consumes 7L/100km.
[c] Based on Renault Clio 1.4 litre, 13800km/year, 10-year life, 10% discount rate.
[d] Assumes current industrial practices. Ranges reflect differences among regions.
[e] Ranges reflect differences among primary energy sources and conversion technologies.
[f] Ranges reflect differences in vehicle technology, maintenance, and operation.
[g] Emissions based on urban cycle, consuming 200-300 Wh/km from mains. Emissions associated with construction of electricity generation facilities and electricity grid are not considered.

Table 7.2 shows that alternative fuel usage in vehicles can offer substantial GHG emission reductions. CNG, LPG, ethanol and methanol already have gained footholds in both developed and developing countries (Sarwar et al., 1999). CNG and LPG can reduce GHG lifecycle emissions by 10 to 30 percent, and biomass-derived ethanol and methanol by up to 80% over gasoline. Reformulated gasoline and diesel are also gaining ground in the developing world (Lovei, 1998). They can affect some decrease in GHG emissions, although the incremental gains are smaller than for most other alternative fuel options.

Hybrid vehicles combining a battery powered system and an internal combustion engine are likely to gain some market share soon, perhaps serving as a bridge to the introduction of fully electric vehicles. Emission benefits of the Toyota Prius, the first mass-produced hybrid vehicle, are 50-90% greater than normal models.

Other potential renewable energy technologies include vehicles that run solely on electric power and internal combustion engines that burn liquid hydrogen. These vehicles can affect decreases of 75% to more than 90% of lifecycle GHG emissions, but these options are currently expensive and may not be widely implemented for many years. To realise such large emissions reductions using liquid hydrogen-burning vehicles, the electricity used to produce the hydrogen must come from a clean source such as solar or wind energy.

GHG benefits-related variations among alternative fuels stem largely from differences in emissions associated with fuel supply and vehicle operation, while there are few differences in GHG emissions associated with vehicle manufacture. Note that emissions from battery powered electric vehicles are almost entirely dependent on type of fuel supply, i.e. the type of electricity generation technology employed. Similarly, producing methanol from coal requires substantial energy inputs, so fuel supply emissions are high in this category. As for emissions associated with vehicle operation, alternative fuels derived from fossil fuels have the highest emissions and biofuels have lower emissions. No GHG emissions are associated with electric vehicle operation (see the Zero Emissions Vehicle Case Study in Chapter 11).

Life-cycle cost calculations show that for vehicles using internal combustion engines similar to conventional gasoline engines, purchase price is not much greater than for gasoline powered vehicles. In these cases, fuel costs determine an option's attractiveness relative to gasoline-powered cars. Thus, ethanol derived from corn, which is much more costly than gasoline, is relatively expensive in lifecycle terms. However, ethanol from sugar cane, which does not cost much more than gasoline, may be less expensive in terms of lifecycle cost in a best-case scenario[59].

An Office of Technology Assessment (OTA) (Ogden et al., 1994) study found that GHG emission impacts and relative costs of alternative fuel options are similar to those compiled in the IPCC survey. (See Section 7.5 for the details of the OTA's study, which includes a specific gas-by-gas accounting, whereas the IPCC report summarizes GHG impacts in terms of CO_2 equivalent). The OTA report also considers local air pollutants such as SOx and particulate matter, and in almost every

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[59] This depends to a certain extent on the techniques used to make the ethanol. If the ethanol is a primary product it may be more expensive than the case where the ethanol is a by-product.

case, the alternative fuel option offers reductions in such pollutants. The exception is battery-powered cars charged by electricity derived from coal. In this case, emissions of particulate matter and SOx are higher than the baseline reformulated gasoline case, but these can occur outside the local area if the power plant is situated some distance away.

7.2.3   Implementation Issues

A number of potential implementation issues exist in the application of alternative fuel options for passenger and goods vehicles. Table 7.3 provides an overview of the current statues, technical feasibility and the potential time frame for the implementation of such fuels, along with the associated environmental impacts for each fuel type. The following section investigates each fuel type in depth.

Table 7.3 ***Characteristics of Alternative Fuel Options for Passenger Vehicles***

Fuel option	EXAMPLES	STATUS	TECHNICAL FEASIBILITY	CONVERSION EFFICIENCY	ENVIRONMENT IMPACT	MARKET POTENTIAL TIME FRAME
Alcohol fuels	Neat methanol Neat ethanol	Demonstration fleets Field trials in large vehicles Commercial availability of blends	Supply limitation and cost needs Change in OEM design Low-cost emissions control option Multiple feedstocks	15% improvement	VOC and CO_2 reductions	0-20 years
Natural gas and LPG	On-board storage System integration	Demonstration fleets Field trials Fuels commercially available	Range extension needed System cost abatement	Close to gasoline with engine adaptation	VOC, CO_2 and particulate reduction	0-5 years
Hybrid vehicles	Battery powered and CNG systems Battery powered and gasoline systems	Demonstration fleets Field trials in niche markets	Adopting hybrid drives can overcome many limitations of current electrical system options	Dependent on base fuel with 20-40% gain possible	Reduction of VOC, CO_2 and particulate vehicle emissions Environmental benefit to be gauged against overall fuel cycle (especially for electrical component)	0-10 years
Hydrogen (in an ICE)	Neat H_2 in ICE storage systems	R&D and prototypes	Infinite source of supply Distillation & production hurdles	Dependent on feedstock and storage system	Substantial reductions in all pollutants	30 years
Electric vehicles	Electric batteries Fuel cells Solar photovoltaic cells Hybrid systems	Demonstration fleets Field trials in niche markets	Range and cost limitations may limit market Adopting hybrid drives may increase use options	Dependent on base fuel with 20-40% gain possible	Reduction to zero of all vehicle emissions Environmental benefit to be gauged against overall fuel cycle	10 years

Ethanol and Methanol

Ethanol and methanol are liquid fuels that can be used with minor modifications in gasoline engines, and in diesel engines with substantial adjustments. The limiting factor for biofuels is fuel price, which varies with the feedstock and related by-products prices. Currently, about one-third of Brazil's automobile fleet runs on pure ethanol derived from sugar cane (Le Rovere, 1998). Box 7.1 presents an overview of the introduction of ethanol in Brazil. Flexible fuel vehicles that operate on methanol, ethanol, gasoline, or a mixture of these fuels, are already being produced in limited numbers in the United States.

Box 7.1 Ethanol In Brazil

Brazil has developed the world's most extensive ethanol production programme. Today, the country produces 13.74 Gl (billion litres) of ethanol per year (Le Rovere, 1998). 4.3 million cars run on pure ethanol, consuming 9.47 Gl of Ethanol per year. The remaining 4.27 Gl of ethanol is used to produce gasohol, an ethanol-gasoline mixture that can be used in conventional engines without modification. Brazilian ethanol use is responsible for a large net decrease in GHG emission. For example, in 1996 ethanol use as a fuel resulted in reduced carbon dioxide emissions equivalent to 12.74 million tons of carbon equivalent (Macedo, 1997). In Brazil, ample supplies of sugar cane crop wastes (e.g. bagasse) meets ethanol energy input requirements. Carbon absorbed by the sugar cane as it grows compensates for carbon released when bagasse and ethanol are used as fuel.

The ethanol industry in Brazil began during the 1970's when the government sought ways to reduce economically draining gasoline imports during a crash in the world sugar market and a foreign-debt-servicing crisis. Rapidly increasing oil prices lasting until the mid-1980's, punctuated by two oil crises, redoubled the government's commitment to ethanol. Initially, the government paid subsidies of up to 75% for investment in ethanol production and assured a 6% return on the investment (Sathaye et al., 1988). In this first phase of this effort, producers sold a 20% mixture of ethanol that could run in gasoline engines without modification. The government began subsidising prices in 1979, ensuring that ethanol would be less expensive than gasoline to consumers. Government offered subsidies on cars running on pure ethanol, and consumer demand exploded.

Despite ethanol's success to date, the future of Brazil's ethanol industry is uncertain. In 1988, nearly 100% of cars sold in Brazil ran on pure ethanol (Le Rovere, 1998). The percentage of ethanol-powered new cars decreased to almost zero by 1997. Falling oil prices in the 1980's led to the end of government subsidies for ethanol production. However, consumer price incentives (at the pump) have remained in place. Ethanol demand outstripped supply, and limited production capacity led to an ethanol supply crisis from 1989 to 1990, damaging consumer confidence (Le Rovere, 1998). The Brazilian government is currently seeking foreign investment in order to continue to provide ethanol production and to provide incentives for its use.

CNG

Compressed natural gas (CNG) is one of the cleanest burning fossil fuels, leading to reductions in carbon emissions of about ten to thirty percent. Impacts on local air pollutants are even greater. CNG can be used in gasoline engines with only minor modifications and little additional cost (Moreno and Bailey, 1989). Diesel engines can also be redesigned to use CNG, which increases vehicle cost by about ten percent above that of a standard diesel engine (Le Rovere, 1998).

Transporting, storing, and delivering CNG is currently a barrier to its widespread use. Most developing countries do not have natural gas supply infrastructure, and constructing such a system is costly. Another problem is the possibility that lower emissions from the exhaust pipe will be offset by leakage during production and distribution. One solution to the lack of a developed distribution system is the production of "bi-fuel vehicles," which can be readily switched from one fuel to another. One popular option is to combine CNG capability with the capacity to burn conventional gasoline.

LPG

Liquefied Petroleum Gas, commonly referred to as propane although it also contains other gases, is a non-toxic by-product of petroleum refining or natural gas production. Usually in a gaseous form, propane turns to liquid under pressure. LPG has been used as a transportation fuel for decades (IPCC, 1996a). In the United States, where no significant barriers to implementation exist, there are more LPG vehicles than all other alternative fuel vehicles combined. One popular option is a bi-fuel vehicle that can run on LPG and gasoline. Bi-fuel vehicles give owners the convenience of utilising LPG when it is available and gasoline when LPG is unavailable.

Hybrids

Hybrid vehicles, which combine batteries and an internal combustion engine, offer great promise in the short to medium term. Toyota has introduced a hybrid vehicle called the Prius. However, to date they have been sold only in Japan. Toyota has increased production from 1000 to 2000 vehicles per month and still has not yet filled backorders for the hybrid vehicle. The Prius offers emissions reductions of 50% for carbon dioxide and 90% for carbon monoxide, hydrocarbons and nitrogen oxide (ORNL, 1999). The Prius has an incremental cost of about $1500 in Japan and about $4000 in the United States (Mark, 1999) over the Toyota Corolla, the nearest comparable vehicle in Toyota's product line.

Hydrogen

Hydrogen use in internal combustion engines has an excellent emissions profile, especially if clean renewable energy is used for its production (note that hydrogen is also an input to fuel cell electricity production). Current vehicle technologies are limited in range and require heavy, bulky fuel storage. An even greater barrier is the high cost associated with hydrogen-fueled vehicles. Significant research and development is needed in the areas of vehicle and infrastructure.

Electric Vehicles

Electric vehicles have great potential for reducing emissions in the long term. However in the short term, short range due to limited battery storage and the cost of electricity limit the battery-powered vehicle's market potential. Battery-powered

vehicle-associated wastes are an additional problem in that even battery technologies under development will require special disposal procedures for production wastes as well as for spent batteries. Another barrier to the spread of battery powered vehicle technology is that most developing countries have limited electricity supply. Battery-powered electric vehicles hold special promise in congested urban areas, where most trips are short and electric vehicles' limited range is less problematic. In the longer term, increased vehicle range and expanded, cleaner electricity generation could make battery-powered vehicles more attractive. Many experts also believe fuel cell-powered electric vehicles have great long term potential, however until now fuel cell prototypes for in-vehicle use have been bulky and expensive. Some observers predict that fuel cells will not become economical for up to 15 to 20 years. Emissions benefits from electric vehicles depend on the energy supply emissions. For example, battery-powered vehicles charged with electricity derived from fossil fuel combustion may barely reduce emissions, and in some cases lead to a net increase in emissions compared to conventional gasoline-powered vehicles.

7.2.4   Heavy-Duty Vehicles

Heavy-duty vehicles such as buses and large trucks have operated on CNG, LPG, methanol and ethanol in demonstration programmes and small commercial operations around the world (IPCC, 1996a). While less research has been conducted on impacts of alternative fuel use in heavy-duty vehicles, existing studies consistently indicate that, among currently economical options, fuel switching has no GHG emission benefits. Rather, alternative fuel usage in heavy-duty vehicles may increase GHG emissions (Delucchi, 1993; IEA, 1993; Gaines et al., 1998). Currently economical options include diesel, LPG, CNG and liquefied natural gas (LNG), with LNG preferred over CNG for commercial transport due to its longer range.

Fuels such as ethanol and methanol offer significant emissions benefits, but they are typically used in conventional spark ignition engines. They can be used in more advanced compression ignition engines with fuel additives, but such additives are expensive and currently make this option infeasible for widespread commercial use.

Table 7.4 lists different fuels' lifecycle GHG emissions in CO_2 equivalents which are emissions associated with vehicle manufacture, fuel supply, and vehicle operation.

A more recent study examined differences between diesel and liquefied natural gas in different engine types (Gaines et al. 1998). Their findings confirmed earlier conclusions that alternative fuel usage in heavy-duty vehicles fails to produce GHG benefits (and in fact results in higher GHG emissions). The study also demonstrates that currently the key factor in reducing GHG emissions from heavy duty vehicles is advanced engine technology, such as compression-ignition or direct-injection, rather than fuel choice.

Table 7.4 Lifecycle GHG emission impact of fuel options usage in heavy-duty vehicles

Fuel (feedstock)	Lifecycle GHG emissions/engine output (grams CO_2 equivalent/KWh)
Diesel	792
LPG	905
Natural Gas	1110
Methanol (coal)	1021
Ethanol (maize)	1032
Methanol (wood)	395
Ethanol (wood)	278
Hydrogen	190

Source: Delucchi 1993; IEA 1993.

7.2.5 Summary

A number of alternative fuels exist for use in passenger and goods vehicles. Options such as LPG have been used for many years in the developed world. Ethanol has also been used extensively in Brazil. However, a number of difficulties exist in the implementation of such technologies, and the GHG emission reduction benefit may be limited or non-existent depending on the fuel source or type of energy used to charge fuel cells and batteries.

The next section examines technology options for improved vehicle efficiency, another possible option for the reduction of GHG emissions from the transport sector.

7.3 Technology Options for Improving Vehicle Energy Efficiency

Many technical options exist for improving vehicle energy efficiency, including weight reduction, reducing aerodynamic resistance and improved combustion. These impact on the level of GHG emissions and on the level of local pollutants. A selection of possible options is presented in Table 7.5 below, along with assessments of the market potential and the environmental impact of such measures. In the section that follows, these measures are examined in greater depth.

*Table 7.5 **Characteristics of technological options for improving vehicle energy efficiency***

Technology	EXAMPLES	STATUS	TECHNICAL FEASIBILITY	CONVERSION EFFICIENCY	ENVIRONMENTAL IMPACT	MARKET POTENTIAL TIME FRAME
1. Weight reduction	• Light structures • Bonded/composite structures • Light powertrains	• Commercial/demonstrated • Bonded structures in limited use • Composite materials in most vehicles	• Continuation of improvements • Limited by material properties and relative cost of manufacture	• 0.2 to 0.4% gain for every 1% weight reduction	• Reduction of all emissions in proportion to efficiency gains • Greater effect on acceleration emissions (urban traffic) as vehicle inertia is diminished	• 0-10 years
2. Reduced aerodynamic and rolling resistance	• Drag coefficient reduction • Reduced rolling resistance • Reduced bearings friction	• Commercial potential for improvement in low-friction bearings and lubrications • Low-friction tyros to be tested	• Continuation of improvements dependent on material properties & cost of manufacture • Study on basic physics	• Speed sensitive benefits • Gains of 1-5% possible	• Reduction of all emissions in proportion to efficiency gains	• 0-10 years
3. Improved combustion	• Ceramic components • Ignition systems • Flow dynamics variable valves • Turbine engine	• Incremental improvements	• Good variety of technology • Available technology must integrate with current ICE	• 5-10% engine efficiency gains	• NOx particulate and CO_2 reduction	• 0-10 years
4. Transmission	• Electronic shift • Multistep lock-up • Continuously variable transmission (CVT) electric drives • Drivelines and suspensions	• Commercial/demonstrated technology • CVT available • High power CVT in prototype • Lock-up and electronic control	• CVT/IVT in widespread use in next decade • Hybrid powertrains feasible with CVT/IVT	• 10-15% gain over manual with CT or IVT • electronic drives could further increase this conversion efficiency	• Reduction of all emissions in proportion to efficiency gains • Engine operation optimised, decreasing emissions even more than efficiency improvement	• 0-10 years
5. Accessories	• On-board electronic controls • Constant speed drives • Efficient components	• Demand responsive systems gaining preference • Constant speed systems in demonstrations	• Highly feasible for constant speed • High efficiency accessory systems	• <5% efficiency gain	• Emissions reduction facilitated by on-board electronic controls and sensors	• 0-10 years

7.3.1 Options for New Vehicles

7.3.1.1 Cars

Numerous technical options exist to improve the fuel efficiency of new cars while maintaining their size, and the level of comfort and performance that consumers demand. For a typical car, about a third of the mechanical energy from the engine is needed to overcome aerodynamic drag and rolling friction, and to power acceleration (MacCready, 1993). Since average driving speeds often are low in developing countries, aerodynamic drag may constitute a smaller proportion of the total loss. Technical measures may improve engine performance or reduce energy demand, in effect increasing energy supply. Measures shifting the mix of new vehicles toward more efficient models include reducing vehicle weight, aerodynamic drag, rolling resistance and accessory loss, whilst improving performance of the engine, transmission or drive train. Any changes in vehicle ride and acceleration performance would offset or assist these efficiency improvements.

Virtually all the GHG abatement techniques discussed below also reduce emissions of local pollutants from vehicles. Techniques to reduce aerodynamic, weight, and rolling energy loss permit smaller engine use, which reduces the GHG output per passenger mile of travel. Engine improvements need to be carefully balanced to ensure that fuel economy is not gained at the cost of increased NOx production, or that accessories such as air pumps are not added to control local pollutants, thus adding a parasitic load and reducing fuel economy.

Weight reduction: Advanced materials technology makes weight reduction possible with every new model year. In the United States, weight reduction was key to automobile manufacturers meeting the Corporate Average Fuel Economy (CAFÉ) standards. Between 1976 and 1982, manufacturers reduced the quantity of steel in the average car from 2279 to 1753 pounds (OTA, 1995). Weight reduction in primary components means weight reduction in supporting subsystems. Engine, suspension and brake sub-systems can be lighter since their performance requirements are lower. A rule of thumb is that every pound of weight reduction gains 0.5 pound of secondary weight reduction.[60]

Several factors determine the choice of materials in the manufacture of a vehicle. These include ease of manufacture, cost, performance and safety. Manufacturing vehicles using only lightweight composites is significantly more expensive than using traditional methods for welding and moulding iron and steel. Liquid moulding methods are yet to be perfected in mass production of vehicles. Vehicle safety design requires that the front and rear of the vehicle are collapsible and absorb the energy of an impact, and that the passenger shell is rigid and holds together in the event of a crash. Aluminium is 50% better than steel at absorbing energy, on a pound per pound basis, but this advantage is offset in an aluminium vehicle, which weighs less.

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[60] The EIA-NEMS model (US EIA, 1999) provides data on costs of weight reduction using different materials. For a mid-size American car, weighing about 3100 lbs., more extensive use of high strength alloy steel is already in progress and can deliver a five percent weight reduction at a cost of $0.50 per pound saved (EIA-NEMS). Greater use of composite materials in body panels, low temperature engine parts and vehicle interiors can save an additional five percent at $0.80 per pound saved. Further weight reduction of 15% and 20% can be gained by using aluminum/plastic or aluminum unibody structure at a cost of $1 and $1.50 per pound saved.

Composites are also better energy absorbers but simulating this is difficult, as such it is difficult to quantify the benefits of using composites.

Vehicles carry a weight penalty in developing countries. The chassis and suspension are made of heavier material in order to withstand the carrying of heavier than rated loads and poorer road conditions. This affects vehicle performance and increases fuel consumption.

Reducing aerodynamic drag: Aerodynamic drag is the resistive force of air, which increases as the cube of relative speed of the vehicle and air. Drag depends on the vehicle's frontal area, shape, and body surface smoothness, and is measured by the drag coefficient (Cd), which is the non-dimensional ratio of drag force to the dynamic pressure of the wind on an equivalent area. Typically, a 10% Cd reduction will result in 2-2.5 percent improvement in fuel economy. Most family sedans in the market place today have a Cd between 0.30 to 0.35. Prototype models have been built with a Cd of 0.15 Design elements such as flush glass windows, underbody covers, and wheel skirts can reduce the drag coefficient, but these carry a weight penalty. A Cd value of 0.25 is considered attainable for a car. Pickup trucks and vans have much higher Cd values, often exceeding 0.4.

Reducing aerodynamic drag is only advantageous in situations where high vehicle speeds prevail, such as on a highway. If much of the driving is in congested city roads, as in a developing country, where average vehicle speed may be only a few miles an hour (Midgley, 1994), reducing drag may offer a much lower advantage than in an industrialised country.

Rolling resistance reduction: Rolling resistance is the force required to move the tyre forward and represents about a third of the tractive forces on a vehicle. The ratio of the force to the weight load supported by the tyre is called the rolling resistance coefficient (RRC). The primary source of rolling resistance is internal friction in the rubber compounds as the tyre deflects on contact with the road. Adding silica to tread compounds can reduce RRC by 20% over recent generation of radial tyres. Changing tread materials, shape of the tread, and shoulder and sidewall designs are other ways to reduce RRC. Current cars have an RRC between 0.008 and 0.010 as measured by the Society of Automotive Engineers method (OTA, 1995). There is significant potential for reducing rolling resistance, and a 30% reduction is possible, to an RRC of about 0.0065, which will increase fuel economy by 5%. These improvements are achievable with no loss in handling or in traction or breaking. Similar improvements are possible for vehicles in developing countries as well.

Brake drag, drive-train and wheel oil seals, and bearings constitute other losses. These together account for about a fifth of the rolling resistance. There is significant potential (up to 60%) to reduce these losses as well through rigid callipers, pads and shoes, and downsizing bearings, using low-tension oil seals, and low-viscosity lubricants.

Improvements to spark-ignition (gasoline) engines: The theoretical efficiency of a modern spark-ignition (gasoline) engine is around 45%. Because (1) the combustion process is not instantaneous, (2) there is mechanical friction between piston and cylinder walls, and other components, and (3) there is air flow loss within pipes and

tubes, including that during throttling or pumping, the actual efficiency is much lower at around 20% for the US EPA driving cycle, and around 27% on highways. Combustion efficiency can be improved by improving spark timing, promoting faster combustion, and increasing compression ratios. Mechanical friction can be reduced through rolling contacts and lighter valve train, fewer piston rings, lighter pistons, better ring and piston coatings, and improved oil pumps and lubricants. Pumping loss can be controlled through improved intake manifold design, multiple valves, adoption of lean-burn engines, and variable valve timing. Direct injection stratified charge (DISC) engines address most of the above problems and can achieve a fuel consumption reduction between 17 to 25% compared to a 4-valve engine with simple fuel/air intake.

Reducing transmission and accessory losses: Transmission performance can be improved by providing more gear ratios. Five-speed automatics and continuously variable transmissions are becoming available, and can provide up to 5% fuel economy improvement over a four-speed transmission. Accessory friction loss improvements are possible in belt drive systems, and higher efficiency alternators and electric power steering in place of hydraulic steering can add up to a 2.5% fuel economy improvement.

Costs of combined improvements: Analysis for the US shows that overall, the above improvements can double the fuel economy of an average 1995 US car by 2015 (OTA, 1995). Improvements come at the incremental costs shown in Table 7.6.

Table 7.6 Projected fuel economy improvement and price

Year	Fuel economy (km/l)	Incremental car price (1995 US$)
1995	11.9	
2005	16.5 – 17.7	920-2100
2015	22.6 – 27.0	2550 – 6250

Source: US OTA, 1995.

DeCicco and Ross (1996,) evaluate 20 measures ranging from multipoint fuel injection to lean burn or two-stroke engines, 5-speed automatics to optional manual transmission, tyre and lubricant improvements (see Table 7.7). They estimate that 18 of the 20 options have a payback period of less than five years, and that US new car fuel economy can be improved by 65% at an average per vehicle cost of $770 or at a cost of conserved energy (CCE) of $0.53 per gallon[61].

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[61] Based on US $1993, a 5% real discount rate and a 12 year life.

Table 7.7 Fuel economy improvement and retail price increment for a typical US car

Technologies	Fuel economy benefit and utilisation increase estimates[a] EEA [c] (%)	Retail price increment (1990$) EEA (%)	Fuel economy benefit and utilisation increase estimates[b] L2 (%)	Retail price increment (1990$) [c] L2 [e]	Payback period (yr)[f]
Engine					
Multipoint fuel injection	3.0	75	3.0	75	4.8
Four valves per cylinder	6.6	180	6.6	110	3.3
Friction reduction	2.9	100	6.0	100	3.3
Overhead camshaft	3.0	150	3.0	40	2.5
Compression ratio increase	0	0	1.0	0	0
Variable valve control	6.0	180	12.0	130	2.2
Super- or turbo-charging	0	300	8.0	160	6.2
Variable displacement	0	-	5.0	65	2.5
Idle Off	0	-	6.0	260	8.5
Lean-burn	0	-	.0	75	1.5
Transmission					
5-speed automatic	5.0	110	5.0	110	4.3
Continuously variable (CVT)	6.5	110	6.0	30	1.0
Torque converter lockup	3.0	55	3.0	55	3.5
Opt. Auto trans control	0.5	25	9.0	60	1.3
Opt. Manual transmission	0	-	11.0	60	1.1
Load					
Tyre improvement	1.0	20	4.8	20	0.8
Aerodynamic improvements	4.6	90	3.8	90	4.6
Weight reduction	6.6	150	9.9	150	3.1
Accessory improvements	0.9	13	1.7	13	1.4
Lubricant improvements	0.5	2	0.5	2	0.7

Source: DeCicco and Ross, 1996

a: Estimates are percentage increase in fuel economy when applying a technology to an individual average base year (1990) automobile.

b: For weight reduction, the L2 estimate is based on 20% decreases in average curb weight of 2880 lb (the 1990 average test weight minus 300 lb), adjusted upwards by 100 lb for emissions and safety standards effects. The resulting estimated reduction is 476 lb., implying net cost of 15% in average test weight. Using a sensitivity coefficient of 0.66 yields the fuel economy benefits shown.

c: EEA column lists, for comparison purposes, the fuel economy benefit estimates of Energy and Environmental Analysis, Inc., as discussed in EEA (1991) or Greene and Duleep (1993), relative to a 1987-88 baseline.

d: Increase in MSRP, including manufacturer, delivery, and dealer markups above manufacturing costs.

e: Adjusted estimates are used for our cost-effectiveness analysis. Adjustments are made to reflect average savings from engine downsizing when applicable. We estimate downsizing as potentially applicable to the 43% of the fleet with 6 or 8 cylinder engines plus one-half of the 56% having 4 cylinders, or 71% of the fleet.

f: Simple payback is calculated as adjusted price increment divided by annual fuel cost savings. Annual savings are based on 10,000 miles per year, $1.20 per gallon fuel price, and a base fuel economy of 27.8 mpg with 20% shortfall

Similar estimates of payback period and cost of conserved energy were derived for the UK and a comparison of such estimates is provided by Michaelis, 1997. While the estimates differ in potential savings, they show substantial potential for technological improvement of the kind described above. For an approximately 4% increase of a car priced at $16,000, the estimated mid-range fuel economy improvement could be 25%.

Developing country context: Vehicles currently sold in developing countries vary widely in energy efficiency, depending largely on whether such vehicles are manufactured domestically. Cars produced in China and India have had historically low energy efficiencies, but in both countries new technologies are being introduced, sharply increasing domestically manufactured cars' fuel efficiencies. The fuel efficiencies of cars made by other developing country producers, including those in Mexico, Brazil, and South Korea, meet current international standards for size, accessories, and other factors.

The energy efficiency of automobiles sold in developing countries could benefit from readily available, proven technologies, although at an increased initial cost. Some efficiency features, such as fuel injection, are considerably more complex than current technology (carburettors), and therefore would require differently skilled labour for repair. Some efficiency features offer benefits in addition to fuel savings. Fuel injection is more reliable, does not require adjustment, and results in lower emissions than carburettors (fuel injection, however, requires gasoline with low levels of dirt and other contaminants.) Radial tyres offer improved handling and safety as well as increased tyre life.

Most car-importing developing countries do not exercise direct design control over the vehicles they import or assemble. If they did, these countries could influence the mix of vehicles that they import, and negotiate with suppliers of vehicle components or vehicle designs assembled domestically to increase the fuel economy of the final product.

Cars produced in industrialised countries and exported to developing countries are similar but not identical to those sold in industrialised countries. In general, models sent to the developing world have smaller engines, fewer luxury accessories (e.g. air conditioning), lower compression ratios (to allow for lower octane gasoline) and often do not use proven efficiency technologies - such as fuel injection and electronic engine controls. Fewer luxury accessories increases efficiency, for example air conditioning adds weight and requires engine power. However, the lack of electronic engine controls and other technologies decreases efficiency.

In many developing countries, low vehicle replacement rates suppress fleet energy efficiencies. The reasons for this phenomenon are low labour costs for repair, minimal quality requirements for annual registration, and the high cost of new vehicles. Measures to increase replacement rates—through registration fees that are inversely proportional to age, bounties for old cars, or establishing safety emissions standards— would increase the fleet's average energy efficiency of, but at a financial cost to users. Developing countries' long average car life puts a premium on high energy-efficiency standards of new cars added to the fleet (see the urban area case study in Chapter 5 for an illustration of the GHG and cost impacts of this option).

7.3.1.2   Heavy Duty Trucks and Buses

Trucks and buses are unlike cars in the sense that they are far fewer in number, cost much more, are driven more, and last much longer. Fuel is a much larger fraction of their operating cost[62]. In most countries, these larger vehicles use more efficient diesel fuel and direct-injection engines that are much more efficient than comparable gasoline engines, but emit much higher NOx and particulate levels. Energy losses and the technical measures to decrease them are the same as those used for automobiles, as shown above, but in different proportions. At full load, aerodynamic loss makes up around 45% of total losses, wheel loss 35%, drive-train loss 13% and accessory loss 7% (Gaines et al. 1998). At partial load, aerodynamic loss increases. In developing countries, vehicles are overloaded and speeds are lower, so aerodynamic loss is likely to be a smaller proportion of total losses.

Weight reduction: Use of aluminium and plastics reduces weight in some vehicle parts including doors, bonnets, and grilles amongst others. This could potentially reduce a tractor/trailer's weight by as much as 17% (Fitch, 1994). Another 4% reduction is possible by using magnesium in place of aluminium in some applications. A 2000 lb (about 9%) weight reduction is estimated to decrease fuel consumption by 3%.

Large trucks normally are designed to carry about double their weight as payload, but in developing countries the maximum permitted weight is often exceeded because the operators overload the trucks. A 20% reduction in vehicle weight gives yields modest reductions in energy use – less than 5% due to excessive payloads. In urban operation, the same 20% reduction in vehicle weight might yield 10-15% energy savings.

Aerodynamic drag: The drag coefficient of trucks is estimated at 0.6, which could be reduced to about 0.5 for tractor/trailer trucks, implying a 7.5 to 8% reduction in power. As noted above, this reduction would be much smaller for trucks in developing countries.

Rolling resistance: The potential for improvements in reducing rolling resistance is similar to that for cars, as shown above. Large truck drive-train losses can be significant and can be reduced by replacing the tandem rear axle with a lighter single axle and a tag axle. Improved lubricants for the gearbox, engine and axle provide small improvements, of around 1 to 2 percent, in fuel economy. Improved drive train matching is problematic because of the propensity of truck owners to overload vehicles.

Combined, the above loss reductions can reduce power requirements for a US truck from 3.3 hp-hr/mile to 2.79 hp-hr/mile, or a reduction of about 15% (Gaines et al., 1998).

Improvements to diesel engines: Some techniques for improving diesel engines' fuel economy are adding turbochargers or modifying existing ones, charge cooling, intercooling and after cooling, and injection timing retardation. Advanced diesel

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[62]   This is often around 40%, including the value of the driver's time.

engines are expected to achieve 55% efficiency and reduce fuel consumption by 16%. Turbochargers may not be as effective in developing countries, at slow speeds in congested cities.

Costs of combined improvements: Sachs et al. (1991) reported the costs of improving heavy truck fuel economy. These results are shown in Table 7.8 and Figure 7.1. Assuming a baseline fleet fuel economy of 5.2 mpg, Sachs et al. estimated that this could be improved to 8.7 mpg, or a 67% improvement, for a cost of conserved energy under US $1 per gallon for each of the seven measures.

Table 7.8 Cost of fuel economy improvement for heavy trucks, 1990-2030

| Technology	Cost ($)	Lifetime (km)	Km/l Benefit	Penetration	Fleet km/l	CCE ($/l)
Drive train	1	1210000	7%	100%	2.4	0.000
Aerodynamics-tractor	3000	1210000	14%	48%	2.8	0.055
Engine control technologies	4000	1210000	16%	100%	3.2	0.062
Aerodynamics-trailer	2000	1210000	5%	48%	3.3	0.090
Tyres	700	130000	8%	100%	3.4	0.165
Engines in development (a)	10000	1210000	10%	100%	3.7	0.238
Weight reduction	3000	1210000	1%	100%	3.7	0.656
Speed reduction (b)	15000	320000	15%	55%	3.9	1.28

Source: Based on Sachs et al. (1991), Figure 1.

Note: Assumes a baseline fuel economy of 7.1 km/litre and a 3% discount rate.

a. Includes turbocompounding, bottoming cycles, and low-heat-rejection diesels.

b. Not a technology, but rather the cost of longer driving times.

Figure 7.1 Cost of fuel economy improvement for heavy trucks, 1990-2030
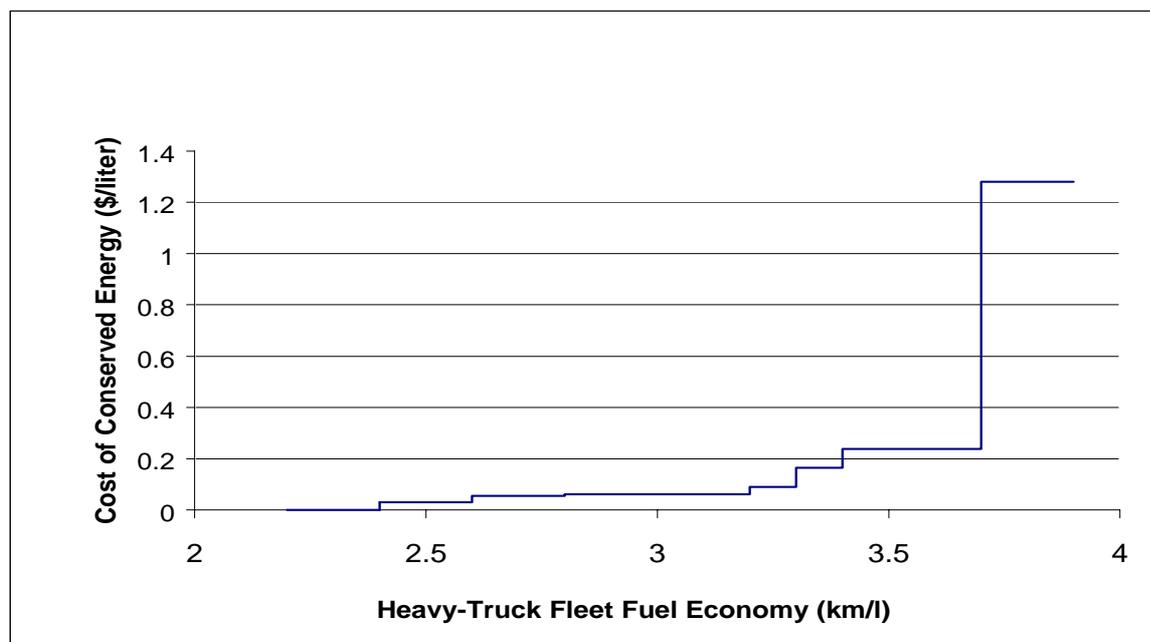
GHG abatement and local pollution control: As in the case of automobiles, GHG abatement techniques to reduce aerodynamic, weight, and rolling energy loss will permit smaller engine use, which would also reduce local pollution. NOx and particulates are the primary local pollutants in the case of diesel engines. Higher combustion temperatures increase fuel economy and reduce particulate emissions, but these also increase NOx emissions. Engine modifications, exhaust control technologies and reformulated fuels are three strategies to reduce NOx and particulates, which need to be carefully balanced to ensure maximisation of fuel economy (Mark and Morey, 1999).

Buses - Special consideration: Buses are typically used for urban and inter-city transit by centrally managed institutions, generally driven by trained professionals and operate over fixed routes. Technological improvements in buses therefore may be easier to demonstrate and their fuel economy improvements more easily monitored than in the case of trucks. Fuel economy improvements (see above) apply to buses equally well as they do to trucks, but because of their urban operations, buses may need to adhere much more stringently to local air pollution standards. Bus fleets in many cities in industrialised and developing countries are currently testing alternative propulsion systems – fuel cells (GEF—China example) and diesel hybrids, and alternative fuels, such as natural gas. One cost study suggests that in the US market, CNG buses have much smaller incremental costs than LNG or alcohol fuel buses (NREL, 1996). Obviously, costs will vary by location and by alternative fuel subsidies.

Developing country context: The trucks used in developing countries are, in general, older, smaller, and less technologically sophisticated than those in the industrialised countries—all factors that result in lower energy efficiencies. Developing-country truck fleets are older because vehicle replacement rates are much lower than in industrial countries. It is usually cheaper and easier to repair and patch up a vehicle than to replace it. The long lifetimes of trucks in the developing world emphasises the importance of building efficiency into new trucks, as these trucks will continue to operate for many years. In general, it is not easy to retrofit trucks with efficiency improvements once they are operating. An exception is periodic engine rebuilding. If this rebuild is done with more modern technology, such as improving fuel injectors and injection pumps, using turbochargers could provide a 10-15% benefit in fuel efficiency, where the road quality does not adversely affect energy efficiency (OTA, 1995).

Truck size is central to its energy efficiency. Generally, small trucks require more energy than large trucks to move a ton of freight. On average, trucks in developing countries are smaller and less technologically sophisticated. Chinese trucks are rated mostly 4 to 5 ton, and the largest Indian trucks are typically rated at 8 to 9 tons (although they routinely carry up to 14 tons). Energy benefits of state-of-the-art technologies may not be fully realised under developing country conditions. Poor highway infrastructure in many developing countries constrains larger truck use. Increases in truck carrying capacity and the energy efficiency advantages resulting from it cannot be attained without improvements in road conditions.

High-efficiency engines are often dependent on high-quality fuels, and do not respond well to the variable fuel quality found in developing countries. Maintenance is more

complex and more critical to engine performance. Further, the cost-effectiveness of the various technological options for truck operators may be compromised by energy pricing policies that keep diesel prices as low as possible.[63]

To summarise, a number of measures exist to improve energy efficiency in heavy duty vehicles. These include measures to reduce the weight of such vehicles, to reduce aerodynamic drag, to reduce rolling resistance and to make improvements to engines. Such measures have an impact on GHG emissions and on emission of local air pollutants, which were identified as having health impacts in Chapter 6. However, the implementation of some of these measures may be hampered in the developing country context due to lower replacement rates.

7.3.1.3   Two- and Three-Wheelers

Two- and three-wheelers are responsible for a large fraction of total gasoline consumption, particularly in Asian cities. Such vehicles are inexpensive and thus provide a popular means of personal transportation for growing urban populations. In the early 1960s, virtually all but the largest motorcycles had two-stroke engines since they are inexpensive, simple to manufacture, produce more power for a given displacement, and require less maintenance. Two-stroke engines have emissions, largely resulting from unburned gasoline, that are 10 times greater and fuel efficiencies 20 to 25 percent lower than four-stroke engines of equal or similar power.

Improved technologies that could drastically reduce emissions and fuel consumption are available at high initial cost. Improved carburettors and electronic ignition could improve efficiency by 10 to 15 percent, and would reduce hydrocarbon (HC) emissions by 50 percent. Four-stroke (as opposed to two-stroke) engines would reduce HC emissions by 90 percent and increase fuel efficiency by 25 percent (see Table 7.9). The increased initial cost for this technology is about $100. At a gasoline price of $1.50/gallon ($0.40/litre) the simple payback period is about 1.6 years, even without accounting for environmental benefits, assuming 10,000 miles/year represents the annual mileage and efficiency increase from 50 to 63 mpg.

Table 7.9 Comparing performance characteristics of two- and four-stroke motorcycle engine

Engine size (cm^3)	Engine type (stroke)	HC (g/km)	NO$_x$ (g/km)	Fuel economy (km/l)
400	2	11.1	0.1	21
500	4	1.2	0.1	28

Source: Energy and Environmental Analysis (EES) 1990

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[63] For example, the installation of a turbocharged engine at a $800 to $1,000 premium for a relatively small (5 percent) benefit in fuel economy is cost effective, but only marginally so: a truck achieving 10 miles per gallon (23 litres/100 km), driven 40,000 miles (64,000 km) per year, and paying $1/gallon ($0.26/litre) for diesel will have a payback of about 4.7 years on such an investment (OTA, 1992).

7.3.1.4   Rail

Railway systems carry a significant fraction of freight only in India and China. Both countries are phasing out older coal locomotives, as diesel locomotives are about five times more energy efficient than coal locomotives. There appears to be no decisive energy benefit in switching from diesel to electric locomotives, which in any event tend to be economically efficient only for high traffic densities.

In addition to switching to diesel and electric locomotives, rail freight energy efficiency can be improved by increasing the average trip length, with fewer stops, greater sustained speeds, operations and communications improvements and technical improvements, such as flange lubrication, improved wheel-slip detection and better aerodynamics. The US example suggests that better planning and operations may yield much higher savings than technical improvements - 85% of the energy savings between 1972 and 1992 in the US were achieved through non-technical improvements, by increasing ton-miles per car-mile (i.e. by better utilising each car,) (Greene and Fan, 1994).

The railway network is playing an increasingly smaller role in inter-city passenger transport, but its role in intra-city transport is increased as subways and metro-systems are built in many major cities of the world. A shift of commuters to urban rail systems can increase fuel economy, provided the shift is from vehicles with low load factors. In developing countries, urban rail either may move commuters from buses to rail, or simply increase the level of service provided to commuters, which might not lead to an improvement in the fuel use per passenger-km.

7.3.2   Options for In-Use Vehicles

In-use road vehicles can be retrofitted to improve their fuel efficiency. Improvements in existing fleet efficiency will be possible through proper engine and tyre maintenance, changes in road surfaces, changes in traffic flow, transportation system management measures, improved traffic signal timing, increased vehicle load factor, changing routes or schedules, or increased back hauling, improved training and performance. Estimating the effectiveness of these actions can be difficult. Some of these options, such as improving traffic flow, involve actions that may reduce emissions only in the short term, but questions remain about how long such savings will last, or what may be required to maintain them.

Regular maintenance: Preventive and remedial maintenance carried out on a systematic basis is essential for safety and vehicle reliability, but also to maintain high fuel efficiency. Good practice in fuel management (i.e. systematic monitoring of vehicle fuel consumption), optimising tyre equipment and pressure, driver training in drive-for-economy and maintain-for-economy skills, preventive and remedial maintenance, (equipment, training, etc.) are all low-cost, short-term fuel saving measures that can reduce fuel consumption by 10-30%. An ongoing GEF project in Pakistan assumed a 6% fuel savings from engine tune-ups (see the attached case study).

Replacing gasoline with diesel engines: Using light-duty diesel engines generally has been encouraged in European countries due to higher energy efficiency from such engines (around 15-20%). During the 1970s and early 1980s, high gasoline prices in developing oil-importing countries encouraged many commercial vehicle owners to switch to diesel (Sathaye and Meyers, 1986). Diesel engines produce higher quantities of NOx due to their high combustion temperatures, and higher particulate levels. Both are serious pollutants in urban areas in developing countries.

There are a number of developing countries where gasoline engines are prevalent in truck fleets. For example, approximately 80% of China's truck fleet uses gasoline engines (Motor Vehicles Manufacturers Association, 1990). Substituting the more efficient diesel engine in the mid-size truck and bus fleets could bring about significant energy savings (He et. al., 1993).

Reducing rolling resistance: Replacing bias-ply tyres with second-generation radial tyres (currently in use in the US) have the potential to halve tyre rolling resistance. These changes could be achieved relatively easily and could reduce fuel consumption by about 10%.

7.4 Approaches to Transportation System Management

This section describes a framework of programmes and measures for transportation system management, whose goal is to use the existing transport infrastructure more efficiently. Measures seeking to enhance or restrain capacity and throughput are "supply side strategies," (TSM), and measures aimed at managing demand for movement are called "demand side," (TDM), strategies. The effectiveness of these approaches may be considerable in the short term but difficult to prove and sustain on a long-term basis.

7.4.1   Transportation Supply Management (TSM) Strategies

Transportation Supply Management (TSM) strategies have two goals: to alter the conditions of road traffic to improve the efficiency with which vehicles operate and to improve the environmental impact of motor vehicles that have implemented TSM measures to restrain motor vehicle operation, often in favour of alternative modes of transport.

TSM strategies to enhance capacity and through-put include constructing new roadways or widening existing ones, construction of or conversion to high occupancy vehicle lanes, urban street and parking management for efficient goods delivery, computer-controlled traffic management (including Intelligent Transportation Systems) and traffic signal timing to enhance throughput or otherwise alter flows into bottlenecks. Rabinovitch (1993) assessed the extent to which lane segregation measures produced a reduction in energy consumption in Curitiba (Brazil), finding that a 20% increase in bus users represented savings of 27 million litres of fuel per year.

TSM strategies that <u>enhance traffic flow and operations</u> allow vehicles to operate at more optimal conditions, which reduces per-kilometre fuel costs. In addition, policies to enhance vehicle flow generally reduce travel times, which reduces variable costs per-kilometre even further. These effects might increase average number of trips, distance per trip, or shift the modal structure toward automobile use. In short, traffic-easing TSM measures simultaneously induce more traffic through better overall travel conditions. Increased traffic potentially means more cars and trucks relative to other modes and an overall increase in travel activity. The net effects on fuel intensity, GHG emissions and local air pollutant emissions are unclear.

TSM options that <u>restrain vehicle flow and through-put</u> include: barriers or prohibitions of vehicular traffic in certain locations or at certain times of day, circulation rationing or licensing, and traffic "calming". *Traffic calming* is the popular name for road design strategies that reduce vehicle speeds and volumes, including measures to narrow streets, introduce horizontal alignment shifts, increase stops, apply contrasting and textured road surfaces, and increase bicycle and pedestrian activity along roads. Some newly developed areas in developed countries are experimenting with road patterns designed to discourage high volume traffic, and with new types of roads, streets and public spaces.

7.4.2   *Transportation Demand Management (TDM) Strategies*

Transportation Demand Management (TDM) includes a variety of measures to reduce transport level and change transport demand type by increasing travel choices and providing incentives for individuals to maximise the utility derived from each mode of transport. Examples of TDM strategies include improving telecommunications, transit-oriented developments, land development, encouraging switching modes, ride-sharing promotion, and transit user subsidies, congestion pricing and other pricing schemes and reducing free and subsidised parking. Chapter 8 provides more in-depth discussion of pricing schemes.

TDM can be highly effective if implemented with sufficient resources and co-operation. 20% reductions in motor vehicle travel are possible and often are much lower than the cost of increasing roadway capacity. Evaluating and prioritising TDM measures are highly dependent on programme goals and analysis.

Most current TDM programmes in developed countries include <u>targeted commuting</u> because it is relatively easy to manage and balances peak period travel. To achieve other goals, such a CO_2 mitigation, air pollution reduction or enhanced travel options for non-drivers, it is necessary to target all kinds of non commuter-related vehicle travel.

The principal advantage of public transit as a TDM measure is that it can move more people more efficiently than private transportation, in terms of both energy and road space. Improving public transit schemes is an effective tool for addressing congestion and CO_2 emission reduction only when passenger occupancies are above a certain threshold, and even then, only when transit enhancements induce mode switching as opposed to solely inducing increased service levels.

Table 7.10 summarises options for transportation system management. It shows examples of where transport system management can be applied to reduce emissions by encouraging better use of resources.

Table 7.10 Summary of transportation management approaches

Category	Examples
Capacity and throughput-enhancing transportation supply management strategies	New road construction Widening of existing roadways. Creation of High Occupancy Vehicle lanes Street and parking management for more efficient goods delivery Computer controlled traffic management, including traffic signal timing
Flow and throughput-restraining transportation supply management strategies	Barriers or restrictions to traffic access Circulation rationing or licensing Narrowing streets Increasing stops Applying contrasting and textured road surfaces
Transportation demand management	Increased telecommuting options Transit-oriented, compact, and mix-use development Ride-sharing promotion Transit user subsidies Congestion pricing Reduction of subsidised parking

The following transportation planning case example from the Randstad region of the Netherlands illustrates TSM and TDM impacts on CO_2 emissions. One particular type of TSM package, designed to increase road construction, shows a CO_2 emissions increase. Table 7.11 shows the study results[64].

As can be seen from the table, three of the four measures reduce traffic (as measured by the traffic index), increase speed and reduce CO_2. As such these should be preferred options for transport programs, particularly if global concerns are taken into account. For CO_2 reduction, pricing turns out to be the best option.

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[64] The Randstad study considered the costs and effects of four packages of measures in addition to individual measures.

Table 7.11 **Effects of combined measures in the Ranstad case study**

		Urban areas	Netherlands total			
Case	Description	Traffic Index	Traffic Index	Speed Index	CO_2 Index	Cost (bn Gld)
1	Parking control package (higher fees, limited area plus improved public transport)	92.7	94.3	102.4	94.4	7
2	Price policy package (fuel price increase, road pricing and parking fees plus improved public transport)	83.0	83.7	102.1	83.3[65]	7
3	Do-nothing package (no investment in roads but improve public transport)	85.0	94.6	103.9	94.7	7
4	Meet-demand package (invest in roads to meet demand and improve public transport)	109.5	104.6	97.4	104.3	14

Note: 1Gld = US$0.569 in 1992.

In addition to these overall effects, Michaelis et al. (1997a) found that:

- Parking control measures can have unexpected results. People making short trips are more likely to be discouraged by parking difficulties than those making long trips. Displacing short-trip traffic, where parking capacity is a constraint, creates more parking space for long-trip traffic.
- Fuel price increases result in a greater decrease in vehicle-kilometres overall than in the urban area. Higher fuel and road use costs tend to reduce long trips, freeing road capacity in the urban centres for more short trips. Improved public transport mainly attracts long-distance commuters and so affects the system as a whole more than urban areas.
- The "do-nothing" package reduces the traffic index by 15% in urban areas, as increased congestion discourages car use, but only 5% overall in the region.

Transportation demand management strategies (TDM) may be effective tools for transport programs. However, as is shown in this section, some of the strategies that may be considered have negative impacts on emissions of global and local pollutants. Issues such as these should be taken into account in the design of transport systems, as they are important contributors to pollutant emissions and hence environmental damages.

7.4.3 Strategic Transportation and Land Use Planning

Demand for commuter and goods transport is determined largely by land use patterns. In rapidly growing regions, ability to control and direct physical settlement patterns is probably the single most important tool to control and restrain long-term transport

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[65] Ibid.

sector energy consumption. Concerted, long-term, region-wide planning and land-use/transport co-ordination can lead to sustainable travel choices and potentially to sustainable GHG emissions reduction and avoidance. Empirical research suggests that land use planning can effectively influence travel choices away from CO_2-intensive modes of transport. Land use actions include the introduction of incentives to induce local and regional governments to use varying degrees of regulation, accessibility-enhancing planning, land-use zoning and formalisation of informal housing development as transportation policy.

Population density, particularly in urban centres, has spurred years of research in transport planning, including the environmental advantages of compact urban settlements. The work of Newmann and Kenworthy (1989) argued there was a high correlation between density and per capita gasoline consumption, though their study has been widely criticised for its methods and conclusions. Recent research considers other tools and aspects of urban form as potentially effective at inducing sustainable travel behaviour. Such behaviour may be induced through improved land-use mix, orientation of buildings toward the street, street pattern and layout, street width and other urban design characteristics.

In the longer term, careful attention to the physical layout of residences, employment centres, and services could reduce the length or frequency of trips or the needs to use personal vehicles (Birk and Zegras, 1993). Locating employment closer to residences, locating public services (e.g., shopping and recreation) closer to intended users, siting major freight terminals away from congested city centres, and controlling the density of land occupation (as is done in Curitiba, Brazil and Bombay, India) could reduce travel needs. Long-term emission reductions resulting from land-use planning are especially promising for developing countries, where cities are growing rapidly and may not yet have adopted extensive automobile use.

Strategic transportation and land use planning may be useful as a mechanism for stimulating GHG reduction. Through the better design of urban residential areas and strategic planning, transport requirements, and hence emissions, can be reduced. The next section examines the extent to which regional transport agencies and the development of transport master plans may be effective in bringing about GHG reductions and build on the gains from strategic planning.

7.4.4   Regional Transport Agencies, Master Plans

The range of options available for greenhouse gas reduction from transportation planning extends beyond the realm of what has been considered "traditional" transportation planning potentially encompassing housing, land-use and economic development as well. Much of the opportunity for influencing the built environment lies in the domains of economic development or housing policy, often at the regional or sub-regional level.

A handful of metropolitan regions in the world have had progressive, farsighted planning and urban development policy vis-à-vis transportation and land-use, and most of them are in industrialised countries. It is difficult to prove that this progressive planning has had a positive effect on transportation energy consumption

in these regions for several reasons. First, there is no base case for comparison. Second, it is difficult to know whether the resulting land form directly influences transportation energy consumption, or simply focuses and channels other factors, such as demographics, which are in turn the more powerful explanatory variables behind observed differences in energy consumption. Finally, planning and control over land use and urban form are often carried out in concert with other policies (such as transit enhancement), so isolating its effects is difficult.

Evidence from around the world suggests that rapidly growing regions that considered land use and growth as part of a larger transportation strategy have reduced transportation energy consumption. Gorham (1996) shows that transportation-related carbon output per capita in the Stockholm, Sweden Metropolitan Region is about one fifth of that in the San Francisco Bay Area, and that most of the difference is attributable to differences in urban form (neighbourhood and regional structure).

Outside the developed world, land-use controls have been effective in Curitiba (Brazil), Singapore and Hong Kong. Singapore and Hong Kong have both successfully implemented joint development strategies as part of their metro system development. Singapore (see Box 7.2 and Table 7.12 below) has undertaken the development of high-density, satellite suburbs as part of its heavy rail implementation strategy in addition to other TDM measures. Both Singapore and Hong Kong have focussed on development of rail transit systems. Curitiba, on the other hand, has focused its development on bus-transit corridors, with high-density residential and commercial development encouraged along the corridor. Population density falls off with distance from the transit corridor. This results in over 60% of the residential population living within walking distance (usually taken to be about ¼ mile or 400 meters) of the transit line (Rabinovitch, 1993).

Box 7.2 Singapore: The Area Licensing Scheme[66]

Singapore is a small island state with 2.8 million people in an area of 633 km^2 (44/ha). Since the early 1970s, it has adopted measures to control traffic problems associated with high population density and rapid economic growth:

- Settlement planning is systematic, with co-location of homes, shops, schools, recreational facilities, factories and offices in each of 17 new towns or housing estates.
- Computerized traffic signal systems have been widely implemented in the central business district (CBD)
- The Area Licensing Scheme (ALS), a cordon charge scheme introduced in 1975, is aimed at reducing morning peak traffic in the CBD. Drivers were required to purchase windscreen stickers that were checked on entering the ALS zone. The programme immediately reduced the number of vehicles entering the zone during the morning peak and shifted many people's morning commuting habits. The scheme's success led to its extension and inclusion of evening peak hours in 1989, and then to the whole day in 1994. In 1996 an electronic road pricing system replaced the ALS.
- The Weekend Car Scheme was introduced in 1991. Owners of cars registered under the scheme can normally drive only on weekends, and receive a rebate on vehicle registration fees and import duty. They can purchase day licenses to operate their cars during weekday peak or off-peak hours.
- Fiscal measures, including high import duty, vehicle registration fees and annual road tax have been implemented to discourage car ownership. In 1994, import duty and registration fees amounted to 195% of car import values.
- The Vehicle Quota System, introduced in 1990, limits new vehicle registrations. New vehicle buyers must bid for quota allocations in a monthly public auction.
- Road tax increases with engine capacity, encourage purchase of small, energy-efficient cars.
- Fuel tax is approximately 40 US cents/litre.
- Public transport is high quality, with buses providing a 20km/h service. More than half of Singapore's homes and work locations are within 1 km of the 67 km mass rapid transit system.
- The road network has been upgraded and capacity constantly expanded to provide more efficient transport links and maximise road system effectiveness.

Ang (1992) estimated the effect of these measures on traffic and energy use. These effects are shown in Table 7.12. As can be seen from the table, CO_2 emissions have been reduced by 30% over the non-policy case. This is despite the fact that diesel emissions have increased, as gasoline consumption fell dramatically as a result of the policy measures outlined above.

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[66] This section is reproduced from Michaelis et al. (1996a).

Table 7.12 Estimated 1990 fuel consumption in Singapore without car constraint policies

	Gasoline	Diesel	CO$_2$ Emissions (mn. tons)
Actual consumption (million litres)	**741**	**465**	**3.0**
Impact of not having policy:			
Passenger traffic increase	*+153*		
Modal shift	*+218*	*-84*	
Shift to larger cars	*+52*		
Traffic congestion	*+122*	*+77*	
Consumption/emissions without policy	**1286**	**458**	**4.3**
Estimated impact of policy on consumption/emissions	**-42%**	**+2%**	**-30%**

Sources: Ang, 1992,1993. CO$_2$ emissions estimated by OECD.

7.5 Data

Table 7.13 and Table 7.14 list comparative economic aspects and GHG impacts of several alternative fuels relative to reformulated gasoline, based on a study in the United States (US OTA, 1994). In one case, lifecycle emissions for a battery-powered electric vehicle are calculated using the U.S. fuel mix. The electricity generation sources in other countries may not resemble the U.S. fuel mix and concomitant emissions profile. While individual projects' economic and environmental impacts will vary from those detailed below, the tables nonetheless offer some indication as to the various fuels and related technologies' relative state of development.

As can be seen from the tables, cars with electric vehicle systems are, on average, more expensive when compared with internal combustion engines. However, the levelised annual maintenance cost and the total lifecycle costs of these technologies are lower. The impact on emissions depends on the source of electricity, though on the whole electric vehicles have greater impact than internal combustion engines.

Table 7.13 Costs[1] of alternative fuel systems (light duty vehicles)

Fuel System	Retail price of fuel: taxes excluded ($/gal. gasoline equivalent)	Retail price of vehicle: taxes included ($s)	Levellised annual maintenance cost ($/year)	Total lifecycle cost (cents/ km)	Break even gasoline price ($s)
Internal combustion engine systems					
Reformulated gasoline	1.18	17,976	396	21.01	n.a.
Methanol (from biomass)	1.85	17,912	392	22.32	2.04
Ethanol (from biomass)	1.52	17,903	392	21.38	1.64
Compressed natural gas	0.96	19,483	370	20.45	1.26
Compressed hydrogen gas (from biomass)	1.79	24,550	392	24.57	2.97
Electric vehicle systems					
Battery powered EV (250 km range)	2.20 (6c/kWh)	21,179	336	21.15	1.55
Battery powered EV (400 km range)	2.20 (6c/kWh)	26,210	336	22.41	2.07
Fuel Cell-Methanol EV (560 km range)	1.85	21,709	389	19.58	0.89
Fuel Cell-Hydrogen EV (250 km range)	1.79	22,530	376	19.64	0.92
Fuel Cell-Hydrogen EV (400 km range)	1.79	25,091	376	20.09	1.11

Source: OTA 1994

[1]All monetary figures are in US$1991.

Table 7.14 Emissions impacts. Percent change in grams per kilometre of travel for different fuel systems (light duty vehicles)

Fuel System	Feedstock/ electricity profile	% Change in CO_2 equivalent emissions over fuel cycle[1]	% Change in NMVOCs (evaporative)	% Change in NMVOCs (tailpipe)	% Change in CO	% Change in NOx	% Change in SOx
Internal combustion engine system							
Methanol – flex. fuel.[2] (using 85% methanol, 15% gasoline)	Biomass	-83	-58 to -67	-50 to -58	0 to -10	0 to -10	up to -100
Methanol –dedicated – (using 100% methanol)	Natural gas	-6	-81 to -92	-66 to -77	-10 to -30	0 to -20	up to -100
CNG (compressed natural gas) –dedicated	Natural gas	-26	-100	-89 to -95	-30 to -50	0 to -10	up to -100
Ethanol – flex. fuel.[2] (using 85% ethanol, 15% gasoline)	Biomass	-88	-36 to -49	-23 to -36	0 to -10	0 to -10	up to -100
Hydrogen – dedicated	Solar	-82	-100	?? to -99	?? to -99	0 to ??	up to -100
Electric Vehicles							
Battery powered EV	US power mix	-14	-100	-94 to -99	-95 to -99	-60 to -80	More[3]
Battery powered EV	Solar power	-100	-100	-100	-100	-100	-100
Fuel cell EV	Methanol	-94	?? to -99	100	?? to -99	?? to -99	up to -100
Fuel cell EV	Hydrogen (solar)	-100	-100	-100	-100	-100	-100

[1]Note that the percent change reported for carbon dioxide is for the entire fuel cycle whereas other figures are for tailpipe emissions (or evaporative emissions where indicated).

[2] Flex. fuel. refers to flexible fuel vehicles that can run on any mixture of gasoline, methanol, or ethanol.

[3]This option is also the only one to have greater emissions of SOx (and particulate matter) than conventional reformulated gasoline and internal combustion engine technologies. In every other case emissions of SOx and particulate matter will be lower with use of the alternative fuel.

7.6 Summary and Conclusions

This chapter has examined technological and planning options for transport policy, with particular reference to the impacts on emissions of greenhouse gases. A vast array of technical options exist, including the use of alternative fuel sources such as ethanol, LPG and CNG. The application of such measures to the developing country context depends on a number of critical implementation issues, including infrastructure and cost, but the range of technical and planning options suggest that standards and economic instrument approaches to GHG integrated reduction policies have much future potential.

A number of new technologies are in development, including fuel cells, that at present are not economic to implement. However, future developments should significantly reduce the cost of these. In addition to these developments, options exist for the improvement of vehicle efficiency, both through improved design of new vehicles and retrofitting of in-service vehicles. The technical details of the options are discussed, along with implementation issues in developing countries. Potential improvements include reducing aerodynamic drag, rolling resistance and weight of vehicles, all of which have implications for fuel economy and hence emission of GHG and local pollutants.

On the planning side, transport supply management (TSM), including measures to manage capacity, throughput and flow, offers much potential for reduced emissions. In addition, transport demand management strategies (TDM) offer ways of increasing travel choice and changing incentives for the use of less polluting modes of transport. Targeted commuting, which balances peak period travel, is one such technique, as is the introduction or improvement of public transit schemes.

Land use planning can also be used as a mechanism for reducing transport demand and hence GHG emission. Zoning, increased density of population and the physical layout of residential property may all reduce transport demand. In bringing such measures to fruition, regional transport agencies may be effective, as they have been shown to be in Brazil, Singapore and Hong Kong.

8. Policy Instruments and Regulatory Options

8.1 Introduction

The purpose of this chapter is to provide a brief overview of how different policy instruments can be applied to GHG reduction inclusive policies as part of more general transportation policies in the transportation sector. We begin with a review of the "traditional" economic literature on environmental regulation and policy instruments - where global environmental externalities are seen as a public policy problem. A framework for evaluating economic instruments and regulatory options is also given. This chapter also will consider a number of specific implementation issues such as information, administration costs and efficiency in meeting the goals, as well as distributional issues.

8.2 Characterisation of Economic Instruments and Regulatory Options

8.2.1 The pollution control problem

The principal environmental control problem is that private agents, through their activity, impose an environmental externality on a third party and this externality is not accounted for in the marginal production costs facing the private agents[67]. Social costs consequently will exceed the private costs of the activity. This undesirable result argues towards introducing public control policies that use estimates of full social costs to help regulate economic activity.

The social and private cost perspectives are illustrated in Figure 8.1. The line sloping down and to the right is the demand curve (or the marginal benefit curve) for transport. Private agents set their output (or transportation activity) at PQ, which corresponds with private cost PC. The social cost of this transportation activity, (accounting for environmental externalities), is SC, which corresponds to production output SQ. The objective of the social environmental control policy is to give private agents the incentive to reduce their activity - and so reduce the derived pollution - from PQ down to SQ. This can be done either by reducing transportation activity or by reducing the pollution intensity of the activity.

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[67] Externalities are defined by Baumol and Oates in the following way: "An externality is present whenever some individual's (say A's) *utility or production* relationships include real (that is, nonmonetary) variables are chosen by others (persons, corporations, governments) without particular attention to the effects on A's welfare." (Baumol and Oates 1975 p. 17).
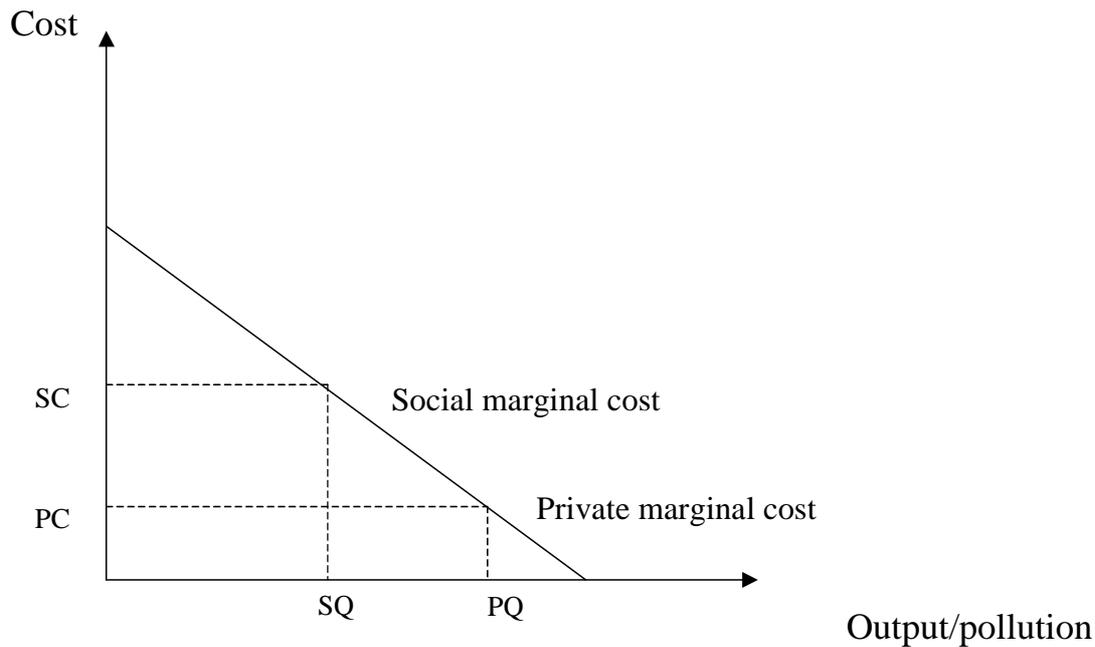
Figure 8.1 Social and Private Costs of Pollution

The environmental regulation may include two main categories of policy instruments:

- *Economic instruments:* these entail the adjustment of production costs and/or consumer prices to reflect social costs. Such instruments include taxes, emission fees etc.

- *Regulatory instruments:* aim at a direct (not price induced) control of the activities that cause the environmental externality. Such instruments include: imposing technical standards, clean technologies etc.

Minimising the total cost of pollution control requires the level of abatement for each source to be determined such that the marginal abatement costs are equal across all sources. Regulatory instruments may only lead to equal marginal abatement cost across sources if the regulatory standards applied to the emission sources are based on detailed information about the abatement cost of the individual polluters.

Damage costs of pollution should determine the quantitative size of pollution taxes designed to shift private costs up to reflect social costs. Great uncertainty about damage costs exists, particularly in relation to climate change. As a consequence, economic instruments used in this area must be designed to incorporate both a general expectation about impacts as well as a political judgement as to what is justifiable.

Economic instruments compare favourably to regulatory approaches in that they are flexible; they allow individual agents to choose between various responses such as investment in pollution control or paying pollution taxes.

However, economic instruments may bring uncertainty to the resulting level of pollution control because the information about control costs, and thereby the

resulting adjustment of activities and pollution, belong to individual agents. Therefore, public authorities may not, ex ante, estimate the actual pollution tax needed to achieve a given target level, instead having to adjust the tax level over time. However, economic instruments may be difficult to adjust for political reasons. Private companies have stated that changes in tax rates impose an uncertainty to prices that make it difficult to foresee future market developments.

Regulatory instruments set pollution reduction targets directly and may be designed, for example, as technical norms for pollution sources such as vehicle exhaust gases. However, such technical standards may be undermined if regulated technical options are replaced by other polluting activities, or if the authorities are too weak to enforce the norms.

Regulatory instruments also leave little flexibility for private agents to select pollution control measures. Another problem relating to inflexibility is the relative inability of these instruments to adapt to changes in desired pollution control levels, technological innovation and consumer tastes. Regulatory instruments like technical standards may stimulate technical innovation to meet specified standards but may inhibit more general technological development outside the regulated area. Similarly, specific technology development programmes may decrease responsiveness to market variations.

Some policy instruments combine flexibility of response and certainty in quantity of pollution abatement. The best known example of such an instrument is the tradable emission quota or permit[68] under which, once the permits have been issued, pollution emitters are able to trade permits to emit, subject to a total cap on physical emissions determined by public authorities. In effect, a tradable permit scheme creates a market in the right to pollute within an overall emission constraint that better reflects social costs.

A tradable emission permit system is primarily effective in controlling emission from large emissions sources where the companies or institutions involved have the capacity to act in relation to an emission permit market. This means that in a system designed to cut emissions from the transportation sector, larger "administrative units" such as the vehicle manufacturers, mass transit companies, freight companies, can be expected to be able to "manage" emission entitlements, whilst, for logistical reasons, this might not be practicable for individual private vehicle owners.

The main tradable permit scheme issue within the GHG emission control context that needs agreement at the policy formulation stage is the basis on which the initial allocation of permits is determined. This issue is likely to be important in determining whether the scheme is accepted by all affected parties, and principally those regulated. For example, if permits are initially auctioned then either national governments or international bodies would collect large revenues from those regulated. If, however, the allowances are initially distributed to the market participants (individuals, firms or governments) initial monetary transfers are avoided.

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[68] Tradable permits are also known as marketable permits. In this book, we use these terms interchangeably.

The allocation formula does not have to remain constant over time. For example, it might be feasible to begin with a formula sufficiently weighted towards current emissions to make it palatable to developed countries, and to modify the formula over time to increase the weight of population.

Tradable permit schemes can be applied within the transport sector. For example, target rates of CO_2 output per kilometre could be fixed for new vehicles. As each vehicle is registered, it qualifies for credits if it performs better than the target value. Alternatively, it incurs a debt if it performs worse than the target value. To reconcile this debt, manufacturers or consumer/purchasers could buy credits.

Details of a possible tradable permit scheme have been drawn up for application to the car fleet in Europe. Initial market simulations of such a scheme clearly demonstrate the cost savings that might be expected to result from its implementation.

It should be noted that a tradable emission quota system is particularly appropriate for GHG emission control because the damages from these emissions are global and non-geographically discriminated. By contrast, in the case of SO_2, NO_x, and particulate emissions, benefits from reducing emissions depend on the site of the emission sources, which must be reflected in a geographically specific tradable emission system.

8.3 Main categories of instruments

Several studies include classifications of policy instruments for GHG emission reduction. (IPCC, 1996b, Chapter 11). We summarise GHG emission reduction policies in Box 8.1. The policy instruments listed in Box 8.1 include options that manage different components of transport sector activity. Options like carbon taxes, road pricing, infrastructure investments, and planning and land allocation policies have a direct impact on transportation activity, while other policies like vehicle-specific taxes, maintenance programmes and fuel economy standards have direct impacts on fuel consumption and technology choice, and an indirect impacts on transport activities. Few of the options listed in Box 8.1 have a direct impact on GHG emissions - this is only the case for carbon taxes and specific technology grants or subsidies. Similarly, where the primary policy focus of the regulatory instruments is GHG emissions, these instruments are likely to have indirect impacts on non-GHG emissions and on transportation activities more generally.

The strong linkages between general transportation policies and environmental consequences make it desirable to assess GHG emission reduction policies in the context of more general transportation development and other multiple planning objectives. Implementing GHG reduction inclusive policies for the transportation sector therefore may become fairly complicated.

Box 8.1 Main categories of potential GHG emission control instruments for the transportation sector

Instrument or Regulatory Option	Focus (Target)	Expected Impact on Transport	Expected Impacts on emissions [1]
Carbon tax	Fuels	Demand decrease Fuel substitution Substitution of transportation modes	Direct impact on carbon emissions Indirect impact on other emissions
Vehicle specific taxes	Vehicles	Demand decrease Substitution of vehicles Substitution of transportation modes	Indirect impact on carbon emissions and other emissions
Road pricing	Driving intensity	Reduced traffic Reduced congestion	Indirect impact on carbon emissions and other emissions
Traffic control systems	Traffic flows	Increased fuel efficiency Reduced congestion Activity decrease	Indirect impact on multiple emissions
Grants/subsidies for technology innovation and penetration (soft loans)	Technologies	Increased technology penetration Reduced operation cost	Direct and indirect impacts on multiple emissions
Vehicle maintenance programmes	Vehicles efficiency	Increased fuel efficiency Decreased operation costs which can lead to increased activity	Indirect impact on multiple emissions
Fuel economy standards	Vehicles efficiency	Increased fuel efficiency Decreased operation costs which can lead to increased activity	Indirect impact on multiple emissions
Exhaust emission control systems	Exhaust gases	Increased capital costs Changed fuel consumption	Direct impact on specific emissions
Public investments or grants to infrastructure (including freight and mass transit)	Supply of transport services by different modes	Mode substitution Activity increase	Indirect impact on multiple emissions
Planning of land allocation and industrial zones	Transportation demand	Activity decrease or increase	Indirect impact on multiple emissions

1. Many policy interventions will impact multiple pollutants. Instruments in this table are said to have a direct impact on specific emissions if the focal control is on these particular emissions. Carbon taxes on fuels are an example of such an instrument. Carbon taxes, however, will also have an impact on other emissions because the taxes through increasing fuel prices will bring about fuel savings.

8.4 Policy Instrument Choice and Design

Relevant information contributing to selection of policy instrument includes:

- Available information about emissions sources and impacts.
- Information about control costs and damage costs.

- Number of emission sources.
- Administration costs.
- Monitoring and verification costs.
- Barriers facing private agents in implementing pollution control policies including market failures, weak institutional capacity, and limited information.
- Political acceptability.

Each of these factors argues for careful specific policy design according to the precise context. A number of these design issues are illustrated in the following sections.

8.4.1 Uncertain Damage Costs

Pollution damages may be uncertain and will occur over long time horizons. The estimation and use of damage valuation is therefore likely to be difficult and controversial when used as decision-making criteria. An alternative approach is to design environmental control policies on the basis of the expected costs of meeting given emission reduction targets. These targets may be determined through various approaches including "safe-minimum standards", "precautionary approaches", or just politically acceptable control costs.

Climate change policy is a good example of an environmental policy area where damage cost information is uncertain and controversial, and which may support the use of emission control cost estimates as decision criteria. In the case of transport this underscores the importance of assessing GHG emission reduction costs for transport options and comparing the results with estimates for other sectors.

8.4.2 Uncertain Control Costs

In cases with uncertain control costs, pre-determining specific emission reduction targets may impose large uncertainties on total reduction costs, so it may be appropriate to specify an "upper boundary" to control costs based on some sort of acceptability criteria.

To date, the transport sector must be classified as having uncertain GHG emission abatement costs. This is because of the relatively few GHG emission reduction costing studies that have been conducted for the transportation sector as well as there being sector-specific complexities in environmental policies. This uncertainty may be an argument for initiating relatively modest GHG emission reduction policies in the transport sector until more solid information about GHG emission control options and related costs for the transport sector is available.

8.4.3 Number of Emission Sources

The existence of many emission sources makes it difficult to use centralised control systems since such systems imply high administrative costs in the implementation and monitoring of each emission source. This difficulty may give weight to arguments for a decentralised control system such as pollution taxes, where individual agents, reacting to incentives, are accorded the flexibility to choose whether to implement the control measure or pay the tax.

Clearly, when only a few emission sources exist, it is much more feasible for the authorities to collect activity-specific information, enabling centralised regulation. However, flexibility of response is lost in this case. For a carbon tax to be an efficient policy instrument, it must be applied consistently across all energy uses, and centralised regulation will not be applicable.

The transportation sector is characterised by a large number of emission sources and the associated difficulties in monitoring. Fuel consumption and GHG emissions are the simplest areas to monitor, which is a strong argument for using carbon taxes as a primary policy instrument.

8.4.4   *Issues in the design of GHG Mitigation Policies in the Transport sector*

Where multiple environmental externalities must be controlled, to obtain a "socially optimal" mix of instruments would require co-ordination of all instruments, where each environmental externality is controlled according to its specific damage (Hoel, 1997). In the case of pollution taxes, this means that the tax on air pollution from urban vehicles should be equal to the sum of the marginal damage values of each pollutant[69]. In practice it is difficult to estimate such damage values. Some of the difficulties are due to uncertainties in the actual measurement of emissions from the various sources, while others are due to valuation issues.

By way of illustration, in the case of an urban air pollution control project the actual composition of an environmental tax that targets multiple pollutants may be considered in the following way: CO_2 emissions are directly related to fuel consumption and so a CO_2 tax may be added to fuel purchase price, while other pollutants like NO_x emissions are tied to both fuel consumption and the combustion process. A tax on emissions such as NO_x needs to include fuel-specific and technology-specific elements.

Determining appropriate non-GHG emissions control levels is particularly complex in the transport sector because damages vary with location of the emission sources and with time. Actual damages from mobile emission sources are difficult to measure. A practical solution may be to specify control levels for non-GHG transport emissions based on a proxy of presumptive damages (see also a discussion of the complexity of urban air pollution programmes in Eskeland and Devarajan, 1996).

An example of an economic instrument that can be used to capture the variety of damages of non-GHG pollutants from transport is road pricing. Most discussions about the potential use of road pricing occur in connection with measures to reduce road congestion. However, it is possible for a road price system to be designed with rates based on actual pollution levels. Since there is no clear efficiency benefit of this scheme over a fuel tax regime, it is most likely that it would be selected only if it were thought administratively sensible to adapt an existing road-pricing scheme to include a GHG emissions problem.

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[69]   In the case with limited market failures

8.5 Political Complexities

In developing countries, where climate change mitigation policies are not seen as a priority, external funding of programmes may be required. Several international funding mechanisms like the Global Environment Facility (GEF) defined in the UNFCCC and the Clean Development Mechanisms (CDM) defined in Article 12 of the Kyoto Protocol establish a framework for financing GHG emission reduction projects. In these cases, however, actual project implementation, in addition to financial resources, must be supported by additional policies at the national level.

GHG emission reduction projects in developing countries affect these countries in terms of costs, income distribution impacts, and joint environmental products. Some of these impacts will be borne by public authorities while others will be borne by individual agents and/or companies.

Including transfers to authorities in project financing is relatively straightforward, but it is more difficult to cover costs imposed upon individual private agents. The following section addresses the categories of control costs that should be assessed in relation to specific climate change policy instruments.

8.6 Issues relating to Control Costs and Benefits

The assessment of control costs should address private as well as public costs, including both costs borne by the private agents (industries, households etc.) as well as the costs borne by public authorities. Box 8.2 shows a taxonomy of environmental control costs for the transport sector.

As shown in Box 8.2, environmental control policies entail planning and administration costs imposed on the government or other authorities, costs imposed on private companies, costs on individual consumers and a number of direct and indirect social impacts. The first category of control costs are the easiest to consider, whilst costs imposed on private companies or consumers can only be assessed on the basis of detailed information about supply and demand functions and price elasticities.

Some environmental control costs can be considered as being of a permanent character while others are more temporary. Permanent costs include capital costs, time losses, and impacts on specific consumer preferences, whilst temporary costs relate to specific transition periods and include unemployment costs, training costs, relocation assistance, and compensation for premature capital retirement.

Using the categories listed in Box 8.2, costs directly borne by individual agents will include time losses/gains, vehicles preferences, joint environmental impacts, general equilibrium impacts and social impacts such as income distribution and access to transportation. This may impose conditions leading to political acceptability problems.

Box 8.2 Environmental Control Costs

Government Administration of Environmental
Statutes and Regulations
Planning
Monitoring enforcement

Private sector compliance expenditures
Capital
Operating

Other direct costs
Time losses (or gains)
Specific vehicle preferences
Shifted management focus (infrastructure)

Direct benefits
Joint environmental and health benefits
Innovation stimulation
Market development

General equilibrium impacts
Employment
Trade
Capital
Property price changes

Transition costs
Training
Early capital retirement

Social impacts
Income distribution
Access to transport services

Source: Based on Jaffe et al., 1995

8.6.1 Distribution Issues

Distribution issues can be important political decision criteria in relation to GHG emission reduction policies in the transport sector, depending on the absolute size of the policy measure in relation to total income. Income distribution issues will arise from two sources. First, adjustment costs that result from policy implementation may affect individuals within different income groups in different ways. Second, the "incidence" of damage costs may vary over different income groups. The nature of the distribution of costs and benefits is described in more detail below. Prior to this, however, it is important to be certain about what benchmark is being used for comparison in any analysis of distributional impacts. The analysis will differ depending on whether we are comparing a carbon tax with no regulation or with an equivalent command-and-control regulation. If the latter, then environmental benefits do not need to be part of the analysis but the regulatory measure needs to be considered.

The "burden", or distributional incidence, of pollution control policies depends on how, and to what extent compliance costs are passed on. For example, a carbon tax increases vehicle manufacturing input costs and increases the market price of fuel

(depending on its content). As a result, lower vehicle use and decreased demand may result in job losses in associated industries.

Following this argument, markets in the transport supply system (i.e. fuel markets, freight or mass transit) allow producers to pass costs to consumers. In developing countries where part of the transport supply system is subsidised, and high- and middle-income families are the primary users of transportation services, increased costs of transport services originating from environmental policies do not necessarily put a burden on low-income families (Shah and Larsen 1992, cited in IPCC, 1996b).

The picture is yet more complex where there is revenue collection, such as from taxes or the permit auctions, which allows revenue to be redistributed to income groups. This is a significant issue in current climate change policy negotiations. The variety and severity of economic redistribution will vary depending on the time scale over which it is evaluated. For example, the standard assumption in economic analysis that in the longer term full employment will be restored neglects the real social costs that result from periods of structural unemployment.

Consideration of the distributional effects of any policy must also consider the benefits of reduced environmental impacts. In the context of GHG reductions this is in fact complicated because some regions such as Eastern Europe and the former Soviet Union may expect to benefit from global warming as their growing season lengthens, thus increasing agricultural production. In the case of local pollution, there may be unequal distribution of benefits because reductions in pollution loads on individuals are unequal over a geographical area and because individuals assign different values to the environmental goods[70]. We also find that primarily low-income families who live in areas with high pollution loads will benefit most from control policies. This benefit, however, may be partly offset if the low-income groups assign a low value to improved environmental quality. Whether these values should be equalised across the world by use of a weighting system is a major area of debate in the development of GHG reduction strategies.

Empirical distributional impact studies on environmental regulations are limited, and differ greatly according to the scale and sophistication of their simulation models. Therefore it is not possible to draw a firm conclusion as to what to expect from a given policy such as a carbon tax. It is important to stress also that the practical barriers to implementation are not only the distributional effects related to income but also on the particular groups such as producers, who may unite and lobby for or against a particular policy.

The way in which environmental control costs may be assessed is illustrated in the following section, using two examples.

1. *Fuel Taxes*
Carbon taxes may be imposed on fuels in order to reduce GHG emissions from vehicles. The tax should be assessed as the welfare loss generated by reduced consumer surplus, corrected for the impacts of specific tax revenue-recycling schemes

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[70] A given reduction in environmental damages experienced by different income groups can be valued differently if an income elasticity of environmental goods are assumed different from unity.

(Eskeland and Devarajan, 1996). The tax burden will be relatively high on old, inefficient vehicles that use carbon-intensive fuels. Transition costs could potentially include compensation for premature retirement of vehicles or soft loans to relax capital constraints.

2. Fuel Efficiency Standards

Technical fuel efficiency standards may be introduced as future mandatory standards. The "early warning" strategy is chosen in order to reduce losses resulting from premature capital retirement and to make investments in R & D and innovation projects more profitable. Actual programme costs depend on the capital stock of the vehicle manufacturers and the cost and efficiency of their R & D programmes.

8.7 Applying Policy Instruments to Case Examples

This section introduces the way in which policy instruments may be used to implement the GHG inclusive policy programme in the context of the case studies presented in Chapter 5. This section should therefore be read in conjunction with that chapter.

Case 1: Urban air pollution control

This case study assesses the additional costs and several joint environmental benefits of implementing an urban air pollution control programme in New Delhi. The study considers a technology mix that includes: conversion to CNG vehicles, use of 4-stroke vehicles, fuel/oil remix, electronic ignition, engine rebuilding, installation of pumpless lubrication systems, periodic inspection and maintenance, and phase out of old three wheelers.

Policy instruments relevant in implementing these technologies include environmental taxes, information programmes, subsidies and specific investments. Some of the options require consumer adoption, which means that the instruments must create incentives for responses in market activities. Programmes that promote engine rebuilding, inspection, and maintenance services may support these economic instruments.

Case 2: Chinese Highway Project

This case study assesses a highway investment project in China with regard to GHG emissions increase, and concludes that this increase is currently an unavoidable consequence of the transportation needs in the country. A portion of the GHG emission increase may be avoided if the highway project is combined with a project that substitutes new diesel trucks for inefficient medium size gasoline trucks. This programme requires manufacturers to supply the diesel engine and local refineries to increase their diesel supply. Appropriate policy instruments might therefore include financial support to manufacturers and refineries and the dissemination of information to truck owners.

Case 3: Road Pavement in Chile

This project introduces new road repair and construction technology to Chile, which is designed to reduce energy consumption and thereby GHG emissions. The basis of this technology is to recycle oil distressed asphalt concrete surfaces.

Policy instruments include direct financial support to the Chilean developers and to the road construction sector. The problem of transition costs - capital losses, unemployment, etc. - of retiring old plants for road pavement could be addressed through specific compensation, information and training programmes.

Case 4: LPG Buses
This case study outlines the impact of replacing existing diesel buses with new LPG buses in Mauritius. A national LPG fuel distribution system already exists in Mauritius, so the main cost of the programme is financing new buses. Additional GHG mitigation-related financial costs for new buses may be integrated into a project programme. It is likely that implementing the project will have a number of local distributional effects on local fuel suppliers, which should be addressed as part of a political feasibility study.

Case 5: Vehicle Maintenance Programme
The GHG mitigation policy added to a vehicle maintenance programme might accommodate the establishment of service centres for demonstration and training for vehicle tune-up to support the service sector. Appropriate policy instruments include information and training programmes and financial support for garages.

Case 6: The Auto-Oil Programme
The Auto-Oil Programme dates back to a 1993 collaboration between the European Commission, the European motor vehicle manufacturing industry, and the European oil industry. One of the programme's goals was to establish fuel and vehicle efficiency standards and to develop a dialogue between the private sector, various NGO's and the European Commission.

This programme has sought to establish a long-term collaboration between the regulatory authority and the private sector regarding future mandatory technical standards, and to share information about technical potentials for environmental improvements, and their costs. This collaboration further seeks to minimise the transaction costs incurred by industry to meet future environmental regulation by agreeing with industry a time-scale in which to adapt to new standards by better focusing R&D programmes. The focus of this policy programme was therefore on regulatory standards.

8.8 Conclusions

The choice of policy instrument(s) that may be introduced in order to bring about GHG reduction objectives is likely to be determined by a number of factors relating to their relative flexibility, their costs, the degree to which they guarantee a certain level of GHG reduction and the distribution of their associated benefits and costs. However, the complexity of this decision will be exacerbated significantly by the fact that the reduction of GHGs will be only one objective amongst a number of other social, economic and environmental objectives that a typical transport policy programme is likely to want to pursue.

As a result of this complexity we suggest that it is of paramount importance that in the evolution of any such programme all relevant ministries and other stakeholder groups

be well versed in the trade-offs that are associated with individual, or combinations of, policy instruments. What this implies, however, is that the trade-offs entailed should be described as clearly and, where possible, in quantitative terms for there to be clarity in the subsequent negotiations. This chapter has highlighted some of the issues that might need to be studied in such an exercise.

9. Global support mechanisms for GHG reduction integrated policies in the transportation sector

9.1 Introduction to Global support mechanisms

The preceding chapters have highlighted the fact that since climate change is a global externality, there is often insufficient will at local or national level to take significant (costly) action to mitigate GHGs. This is especially so in developing countries where governments often do not regard the existing problem as one of their making and thus do not see it as their primary responsibility to undertake expensive mitigating measures. Consequently, if developing countries are to mitigate GHGs external support will be needed. Currently two principal tools are being developed and used to this end: the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), which includes a number of mechanisms designed to facilitate co-operative GHG emission reductions, and; the Global Environment Facility, a financial mechanism established under the UNFCCC. These tools are introduced in this chapter with an emphasis on issues relevant to GHG emission projects in the transportation sector.

9.2 The Kyoto Protocol

9.2.1   Introduction

In December 1997, at the Third Conference of Parties (COP-3) to the United Nations Framework Convention on Climate Change (UNFCCC), over 160 countries adopted the Kyoto Protocol to the Convention, which aims at reducing the emissions of greenhouse gases (GHGs) to the atmosphere by industrialised countries (called Annex 1 parties/countries).

The Protocol calls for a reduction of GHG emissions by industrialised countries at differential rates but at an average of 5.2% from their 1990 levels in the first commitment period (2008-2012). The primary GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

The economies of some of Annex 1 parties to the Convention that have prescribed targets in the Protocol are expected to grow at an average of about 2-3% annually, and their GHG emissions between 1-2% annually based on past trends with no direct climate change policy interventions. The transport sector is a major source of energy-related GHG emissions, growing in most regions more rapidly than emissions on average (Schipper and Marie-Lillieu, 1999), and the integration of this sector in climate change mitigation policies may therefore be important in achieving reduction targets

Some industrialised countries (Annex I countries) expect that achieving the GHG emissions outlined in the Kyoto Protocol with only domestic actions may be very costly and technologically demanding. Provisions were therefore made in the Protocol

for countries to use different mechanisms based on co-operative principles among parties to assist them achieving Kyoto targets. These principles potentially facilitate a sort of international funding mechanism that can be used in combination with other funding mechanisms such as overseas development programmes and other donor-funded programmes, including GHG reduction inclusive transportation programmes.

9.2.2   Kyoto Protocol Mechanisms for Co-operation

The Kyoto Protocol's provisions for co-operative actions are Joint Implementation (JI) in Article 6, and referred to in Article 3.10 and 3.11, the Clean Development Mechanism (CDM) in Article 12, and referred to in Article 3.12, and Emission Trading (ET) in Article 17, and referred to in Article 3.10 and 3.11. JI projects can be carried out between Annex I countries, which is expected to facilitate project financing in countries with economies in transition. CDM projects can be carried out between Annex I countries and developing countries. Emission trading, like JI, facilitates co-operation between Annex I countries.

The three Kyoto provisions (JI, CDM, ET) are similar in their inclusion of GHG offset trading between parties. CDM is similar to JI in many respects but there are three main differences. First, in CDM, the GHG abatement credits should be from projects located in developing countries. Second, abatement credits under JI and ET may be generated and transferred only during the first commitment period, 2008-2012. However, under CDM such credits and transfers may occur from January 2001 onwards. Further, Annex 1 countries' parties can use them towards satisfying their Kyoto targets during the period 2008-2012. Third, CDM projects should promote sustainable development in the non-Annex 1 country in addition to GHG abatement. The CDM has a direct link to all countries, while ET and JI will only be relevant to countries with economies in transition and developing countries that take voluntary commitments.

Several conferences of the parties to the UNFCCC has discussed and adopted specific rules and modalities for implementing the Kyoto Protocol in particular those related to the JI and the CDM mechanisms as well as liability rules and procedures for monitoring and verification of emission reduction. Many factors within these mechanisms still remain to be resolved in subsequent Conference of Parties serving as the Meeting of the Parties to the Protocol (COP/MOP).

Transport projects may be discussed in relation to CDM to the extent that projects in the transportation sector meet the criteria stipulated under the Clean Development Mechanism (CDM). The extent to which this is the case is discussed in the following section.

9.2.3   CDM Issues in Transportation Sector GHG Reduction Inclusive Programmes

As with the other Kyoto agreements, the rules as stated in the Protocol provide flexibility for resolving many options and outstanding issues. Outstanding CDM issues are:

(1) eligibility criteria for projects,
(2) determination of baselines,
(3) auditing, verifying and certifying emission reductions; and
(4) sharing of credits.
(5) liability rules.

Of the issues listed above, the first three raise a number of issues that are very similar to those surrounding GHG integrated policies, and the implications of potentially using the CDM mechanisms to finance such policies are discussed below.

9.2.4   Project Eligibility

Future COPs/MOPs will determine the type of projects for the Kyoto agreements, though project eligibility is likely to be determined based on existing provisions in the Protocol. For example, atmospheric GHG reduction alone will not make projects eligible subjects for these agreements. In the case of CDM, projects should provide real, measurable, and certified emissions reductions based on conditions agreed upon by the COP/MOP whilst promoting sustainable development in the host country.

Since the Kyoto agreements were adopted, discussions have sought to define specific criteria for project eligibility. Some criteria under discussion that possibly relate to CDM-type transport projects include:

- National development parameters in projects to ensure sustainability according to criteria defined by host countries.

- Technology transfer, criteria for selection of technologies (state of the art, well tested and matured technologies, exclusion of technologies considered to be "outdated").

- The role of a national/international authority in determining criteria for project eligibility.

CDM project eligibility also will require specification of the private sector's role (domestic and foreign) in the Annex I countries as well as in the project host countries.

9.2.5   Determining a Baseline

The baseline level is the emissions level below which projects may obtain certified emission reduction credits. Baselines cases for CDM projects are complex because project host countries are not committed to controlling GHG emissions in the Kyoto Protocol.

The methodological complexities surrounding the determination of baselines have been recognised in the on-going discussions on this subject[71]. The level of complexity depends very much on the type of transport sector project. The case studies show that determination of the baseline for infrastructure (road construction) is more straight forward than that of, say, improving efficiency of an existing fleet of buses, or replacing gasoline-operated buses with LPG-operated buses since the latter two examples are surrounded by a high degree of uncertainty regarding future trends in use.

9.2.6 *Auditing, Verifying and Certifying Emission Reductions*

For the credibility of the Kyoto Protocol to be retained it is important to ensure that emission reductions are measured and agreed upon. There are therefore a number of technical and administrative hoops that a project has to pass through in order to establish the reductions within the strictures of the flexibility mechanisms. To clarify terms that are used in this procedure; <u>auditing</u> is the examination of all project level documents relating to the generation, acquisition and transfer of certified emission reductions, to ascertain that calculations are accurate and undertaken in accordance with agreed upon standards. <u>Verification</u> essentially entails checking that emissions reductions claimed in the national and international registers of CDM projects in a country have in fact occurred. <u>Certification</u> is an official declaration confirming achievement of a project in reducing a certain amount of GHG.

Projected emission reductions from a project have to be verified when the project becomes operational to ascertain whether the expected reductions and the actual reductions tally. This is difficult in the transport sector. Unlike power plants, where GHG emissions can be measured related to the fuel consumption and the energy conversion process, mobile emissions sources make monitoring and verification more difficult. Furthermore, most of the transport sector projects involve many actors and many small emission sources, which may lead to high transaction costs for CDM project implementation. Referring to the case example of the replacement of a fleet of gasoline-operated buses with LPG buses as a possible CDM project, once the project is up and running, the projected emission reductions must be compared to the baseline case and certified for the project sponsors to earn emission reduction credits.

9.2.7 *Conclusions*

The Kyoto Protocol's clean development mechanism may include constraints on the range of projects that may be credited with certified emissions reductions, though this is not yet finalised. However, assuming that transportation projects are eligible, it would be useful to establish a common basis for GHG reduction integrated transportation programmes and CDM projects so that the activities meet national development and sustainability priorities as reflected in various reform programmes. A similarity of approach could also be helpful in solving some of the critical issues related to baseline case selection for CDM projects, where national reform programmes made outside the context of CDM could be used as references.

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[71] For a discussion of these issues, see the UCCEE's work on baselines. This is downloadable from www.uccee.org.

Ultimately, the main complexity in using the CDM mechanism to finance GHG reduction inclusive policies for the transportation sector are probably related to the difficulties involved in controlling multiple non-point pollution sources in the sector.

9.3 Financial mechanisms

One potential existing financial mechanism for co-operative GHG emission reduction projects that sits within the Kyoto Protocol flexibility mechanism framework is the Prototype Carbon Fund (PCF), established by the World Bank in July 1999, capitalised with US$ 150 million, and scheduled to terminate in 2012. It aims to demonstrate the possibilities of public-private partnerships, and to offer a "learning-by-doing" opportunity to its stakeholders and has started with a project pilot phase within the framework of JI and CDM projects. The fund has a project portfolio that is geographically balanced and that covers a wide range of technologies, though with a focus on renewable energy. The PCF investment is not only made directly to projects, but will also include assistance to host countries for setting up funds sponsored by commercial and development banks. This increases the diversity of projects, spreads the risk of investment, and increases carbon market trade by underwriting the risk of private intermediaries at an early stage.

The potential for PCF funding of transport projects exists but has not yet been exploited. It is as yet unclear as to whether transport projects will look attractive in terms of GHG emission reduction compared to renewable energy, given some of the difficulties attendant in baseline measurement of transport projects.

9.4 The Global Environment Facility

9.4.1   Introduction

The Global Environment Facility (GEF) launched the Operational Programme number 11: "Promoting Sustainable Transport" in September 1999, (GEF, 1999). This programme is part of the GEF's climate change work that addresses UNFCCC long-term programme priorities. The GEF is one of the potential funding sources for transportation sector GHG mitigation inclusive programmes, and so it follows that the GEF's operational strategy may be central to policy selection. The following section is an overview the GEF's strategy and discusses areas where GHG reduction inclusive strategies and GEF financing may be combined.

9.4.2   Main objectives and scope of the GEF operational programme

The objective of the GEF's Operational Programme for transportation is:
> "to reduce GHG emissions from *ground transport* sources in recipient countries. The objective will be achieved by facilitating recipient countries' commitment to adopt sustainable low-GHG-transport measures, and disengagement from unsustainable measures common in many parts of the world." (GEF 1999, 11.34).

More specifically, the GEF programme will initially promote the following measures in ground transport (GEF 1999, 11.11):

a) Modal shifts to more efficient and less polluting forms of transport;
b) Non-motorized transport;

c) Fuel-cell or battery operated 2- and 3-wheelers that carry more than one person;
d) (Hydrogen)-powered fuel cell or battery-operated vehicles for public transport and goods delivery;
e) Internal combustion engine-electric hybrid buses; and
f) Advanced biomass to liquid fuel conversion technologies.

The GEF will help to accelerate the development, deployment, or full commercialisation of the above-listed technologies or measures. Cost-effective measures that increase the efficiency of current transport systems, but which continue to be based on fossil fuels, must be justified under the GEF's other short-term operational programs for climate change mitigation. In addition, activities that the GEF may finance include strategic planning, targeted research, training, capacity building, technical assistance, demonstration projects, investments and market transforming activities. These activities include support for technical measures as well as strategic urban, land-use and transport planning.

The GEF's operational programme is defined within a general framework for sustainable transport. This is in para. 11.15 of the GEF strategy defined as activities that also provide multiple domestic benefits, which in par. 11.25 are specified to include (among others) reduction of congestion and pollution, creation of new industries, opportunity for technological leadership, and exports.

Initial programme spending is suggested to be $60 million per year in GEF grant resources, gradually increasing to $100 million per year over 5 to 10 years as investment demand and absorptive capacity grow and then reducing as the programme succeeds in its objectives.

9.4.3   The GEF's Strategy

The GEF strategy activities are a sub-set of the areas that are presently covered in current transportation sector activities of international donors. In the OP11 they cluster around a few advanced fuel and vehicle technologies (measures c, d, e, and f in the above programme activity list), of which in particular the fuel-cell or battery operated two- and three-wheelers options are expected to have considerable "side-impacts" on urban air quality. Therefore there is potential to co-ordinate GEF GHG mitigation activities with urban air pollution control programmes.

The GEF OP11's focus on specific technologies may create constraints on GHG mitigation inclusive policies if these specific technical options are very different from those selected on the basis of cost-effectiveness criteria. The basic principle of the GEF funds is to cover the *incremental costs* of implementing the specific GHG emission reduction option, but some of the options may have significant impacts on the costs and broader impacts of other transportation programme components. Therefore, it is necessary to assess the additional costs of the inclusion of GHG mitigation and to compare it with the incremental cost of specific technical options that will be eligible for GEF funding.

9.5 Conclusions

The chapter has outlined three mechanisms that appear to support the possibility of financial assistance to transport projects that incorporate GHG reduction objectives. Global climate change policy, currently shaped by the structure of the Kyoto Protocol, appears to offer the opportunity of support to such projects through its JI and CDM flexibility mechanisms, once the Protocol is ratified. The Prototype Carbon Fund is a World Bank administered resource to support pilot JI/CDM-type projects prior to Protocol ratification that may support transport projects in the meantime. Finally, the GEF Operational Programme 13 is a support programme specific to a relatively narrowly defined range of transport project types.

The level of financial assistance to the transport sector that will be forthcoming from the Kyoto-type mechanisms is very uncertain. It is not yet clear what the scale of potential support from these mechanisms is likely to be over time since the mechanisms are still evolving prior to Protocol ratification. Ultimately, however - and assuming ratification does proceed - it seems likely that the take-up by the transport sector is not going to be determined so much by the technical demands that this sector makes in establishing emission reduction levels, but by the cost effectiveness of these projects compared to those in other sectors.

10. Transport Sector GHG Mitigation: Public-Private Collaboration

10.1 Introduction

This chapter explores potential private sector involvement in environmental policy initiatives. Regulatory efforts in the US and Europe are outlined, and some tentative suggestions are drawn for decision makers in organisations that might want to promote similar initiatives. The suggestions reflect the fact that the global transport private sector encompasses a wide array of activities including vehicle manufacturing, service and maintenance, and component industries - as well as architect and engineering firms engaged in the design and construction of infrastructure.

This chapter is divided into the five sections. Section 2 describes the global industrial sectors with which the funding organisations may collaborate, and outlines the rationale and mechanisms for collaboration with the private sector. Section 3 identifies the means by which direct financial assistance can be implemented in the GHG reduction inclusive context. Section 4 describes how the funding organisations might encourage participation in policy making and summarises lessons for potential funding organisation practice. Section 5 draws broad conclusions from the chapter.

10.2 Characterising the Global Automotive Sector

10.2.1 The Global Automotive Sector: Overview

The automotive sector is a significant component of many economies, particularly those in North America, Western Europe and Japan, which are the world's dominant vehicle manufacturing regions.

Supply
The following three tables show vehicle production levels throughout the world, by vehicle type and by region. Table 10.1, Table 10.2 and Table 10.3 show that the Western European and Asian regions and US, Canada and Mexico together represent 87% of car production, 95% of light truck production, and 89% of heavy truck production. Car production represents about 60% of global vehicle production.

The Global Automotive Sector: Key Data
Table 10.1 shows that Western Europe and Asia are the car largest markets. Japan represents about 70% of Asian production, and the USA produces about 70% of the output from the US/Canada/Mexico grouping. In Western Europe, Germany is the largest single producer at 34%.

Table 10.1 Global Car Production (000s)

REGION	1995	1996	1997	1998	1999	2000	2001	2002
W. Europe	12,612	13,063	13,802	14,156	14,084	14,031	14,253	14,494
E. Europe	1,794	2,065	2,498	2,788	3,059	3,396	3,696	3,948
US/Canada/ Mexico	8,674	8,163	8,133	8,179	8,054	8,016	7,962	8,103
Asia	10,222	11,098	11,901	11,113	11,501	11,579	11,774	11,866
L. America	1,587	1,728	2,046	1,927	2,103	2,307	2,497	2,687
Other	516	565	558	594	616	637	661	681
Total	34,902	36,682	38,938	38,756	39,418	39,965	40,842	41,780

Notes: All figures for 1995 - 1997 represent actual production levels; all figures for 1998 onwards are estimates; All figures have been rounded up to the nearest 1000 units of production; 'Other' refers to Australia, New Zealand and South Africa; Reference: '*World Car Industry Forecast Report*' by Standard & Poor's DRI, 1998.

Table 10.2 and Table 10.3 show light and heavy truck production, the largest producers being the US/Canada/Mexico and Asia. Table 10.2 shows that Asia and US/Canada/Mexico are the major producers of light truck production. China is also a significant producer and accounts for approximately 20% of total Asian light truck production (based on 1997 data).

Table 10.2 Global Light Truck Production (000s)

REGION	1995	1996	1997	1998	1999	2000	2001	2002
W. Europe	1,307	1,405	1,491	1,432	1,444	1,496	1,507	1,494
E. Europe	181	193	208	248	290	318	334	346
US/Can/Mex	6,553	6,958	7,492	7,567	7,763	7,884	8,165	8,399
Asia	4,402	4,403	4,325	3,863	4,082	4,311	4,464	4,603
L. America	290	314	375	379	412	456	496	543
Other	137	142	131	132	133	130	125	118
Total	12,869	13,416	14,022	13,621	14,124	14,595	15,092	15,502

Source: *World Car Industry Forecast Report* by Standard & Poor's DRI, 1998

Table 10.3 Global Truck Production (over 6 tonnes) (000s)

REGION	1995	1996	1997	1998	1999	2000	2001	2002
W. Europe	0.3	301	329	348	343	332	329	334
E. Europe	9	10.2	8.1	8.6	8.5	7	7	5
US/Canada/ Mexico	431	357	421	464	418	389	386	400
Asia	714	681	613	542	601	700	778	813
L. America	75	54	68	64	68	73	78	74
Turkey	18	29	44	44	33	35	39	43
FSU	66	55	55	61	66	75	80	88
Total	1,658	1,488	1,538	1,531	1,536	1,613	1,696	1,758

Source: World Car Industry Forecast Report. Standard & Poor's DRI, 1998

10.2.2 Regional Light Vehicle Production by Manufacturer

<u>North America</u>
The principal North American manufacturers are GM, Ford, and Chrysler have 35.6%, 27.7% and 17.6% of market share for light vehicle sales respectively. Japanese manufacturers Toyota and Honda have 5.4% apiece.

<u>Japan</u>
Toyota, (33% of market share), Mitsubishi (10.8%) and Nissan (16.1%) dominate the markets in Japanese light vehicle production. North American and European producers are not significant in this market.

<u>Western Europe</u>
The VW group holds the largest single market share, with 17%, using 1997 data. Fiat, GM, PSA and Renault all have over 10% market share. Japanese manufacturers have a small presence in the Western European market, with a combined share of approximately 5% of total output.

Approximately 25 vehicle manufacturers dominate global vehicle production, and are concentrated in three geographical areas: Western Europe, North America and Japan. But these manufacturers increasingly regard developing countries as growth areas, suggesting that without stringent import restrictions, these manufacturers are likely to become increasingly dominant in these markets as well.

10.2.3 The supply chain: Key data

The automobile supply chain ranges from raw materials to complex systems. Vehicle manufacturers buy components and systems from suppliers in an increasingly global market. Table 10.4 shows the automobile supply chain in Europe. The totals for North America and Japan are estimated at about 2000 and 1500 respectively.

Table 10.4 European component suppliers

Country	No. of suppliers	Country	No. of suppliers	Country	No. of suppliers
Belgium	250	Denmark	10	France	1100
Germany	800	Hungary	180	Ireland	20
Italy	827	Luxembourg	14	Norway	25
Poland	231	Portugal	180	Slovenia	82
Spain	340	Sweden	160	Switzerland	106
Ukraine	26	United Kingdom	500		

(Adapted from *The International Directory of Automobile Suppliers*, 1998)

Direct suppliers to vehicle manufacturers have consolidated into increasingly large groups, called "first-tier" suppliers, supplying whole systems as opposed to component parts. 'Second-tier' suppliers supply component parts to first-tier

suppliers, while "third-tier" suppliers sell materials for these parts to second-tier suppliers.

As with vehicle manufacturers, a growing consolidation amongst first tier suppliers suggests that the market may comprise only ten companies by 2010. This trend is similar to the increasingly close working relationships between the vehicle assemblers and the first tier suppliers. These trends may affect collaborative strategies. For example, the Auto Oil Programme probably will be more feasible with fewer participants.

In the case of second and third tier suppliers, the numbers of suppliers in individual countries are very high (Schipper, 1999). In many countries in which funding organisations are active, these suppliers operate principally in the informal sector. A policy approach, possibly involving tax credits, is more likely to be appropriate for these suppliers.

10.3   Funding Organisation Collaboration with the Private Sector: Rationale and Potential Operational Mechanisms

We wish to identify whether and how funding organisations should collaborate with the private sector to introduce GHG mitigation strategies. The reasons we consider private sector collaboration are the outcome of two recent trends:

- Recognition that the private sector is likely to be better at mobilising economic and financial resources to achieve a particular policy objective – driven, as it is, by profit and efficiency considerations.

- Perception that it is more sustainable to adopt a more inclusive approach to policy making, in terms of accountability

Potential funding organisations such as the World Bank can and do collaborate with the private sector using two broad mechanisms:

- Provision/facilitation of finance for business operations to support the organisation's policy objectives;

- Facilitation and encouragement of public policy, including business and consumer/citizen sector participation in the policymaking process.

We describe these two mechanisms below and explore them for their applicability to the GHG reduction inclusive context.

10.4   International Funding Organisations as Finance Source/Facilitators to the Private Sector

In this section we describe potential initiatives organisations might consider to harness private finance toward greenhouse gas mitigation in the transport sector. The first three of these initiatives relate to *new* vehicle component production, and the latter two relate to maintenance of *existing* vehicles.

The World Bank Group, for example, uses many mechanisms that facilitate, or leverage, private financing and reduce the perceived risk in capital investments, and many of these existing mechanisms may be used in the transport GHG mitigation context. For example, market resistance met by new transport technologies, (e.g. the ZEV technologies in California, experienced by manufacturers), may be reduced in funding organisation client countries by using an approach similar to the IFC/GEF Poland Efficient Lighting Project, which effectively reduced market barriers to efficient lighting sources. Similarly, the principle of investing in alternative energy technologies advocated in the Investment Fund for Renewable Energy and Energy Efficiency Initiative may be applied to local/regional alternative transportation initiatives.

As outlined in previous chapters, the Global Environment Facility (GEF) and International Finance Corporation (IFC) use existing finance mechanisms to support both domestic and foreign vehicle and component manufacturing enterprises that agree to adopt best-practice emission technologies in new vehicles. This type of initiative will succeed if technological knowledge is transmitted to indigenous producers, and if the investment funds necessary to improve commercial viability are co-coordinated. Smaller component producers and domestic vehicle manufacturers are most likely to receive such support. An alternative approach is to encourage clean technologies by imposing fiscal incentives, which could be promoted with the help of national governments.

Funding organisations might consider making guarantees available in situations where new capital investment by private investors, (e.g. in oil refining changes needed for transport fuel improvements), is deterred by unstable national government policies. The degree and quality of existing vehicle maintenance is critical in determining vehicle emission rates. At present, in many countries where funding organisations operate, garages carry out vehicle maintenance, and many of these garages exist outside the formal economy and therefore are not affected by legislative instruments. Alternative means to contain emission rates in existing vehicles might include:

- Incentives for more garages to operate in the formal economy so that service standards can be more easily regulated, and/or;

- Enforce vehicle inspection on a regular and mandatory basis;

- Develop and implement contracts to make the vehicle manufacturer responsible for providing the maintenance of the vehicle after sale, specifically for vehicle emissions.

Therefore, the following suggestions to funding organisations can be made for suitable action:

- Be sensitive to local and national possibilities for improving vehicle maintenance standards and adopt strategies to reduce emissions most cost-effectively.

- Training programmes should target agencies responsible for regulating maintenance standards at inspection centres.

10.5   Private Sector Involvement in Public Policy

Public funding organisations can encourage private sector involvement in public policy by acting to increase trust and co-operation among stakeholders and allow greater public participation.

One example of a re-balance among stakeholders is that which occurred in California with the implementation of the Zero Emissions Vehicle mandate (see the Case Studies chapter for a detailed description). Originally, the ZEV mandate required the seven largest auto manufacturers to sell 2% ZEV in 1998-2000, 5% ZEV in 2001-2002, and 10% ZEV in 2003 and beyond. Protests from the manufacturers - who regarded the rate of market penetration unrealistic - led to a modification of the mandate. The resolution was to allow for greater flexibility in achieving the desired air quality targets. This result shows the shifting of policy definition, as influential stakeholders affect policy. However, the welfare change resulting from this re-negotiation is unclear since, while air quality improvements are delayed, the increased flexibility of response from the manufacturers may result in resource savings.

The European Auto-Oil programme mandates vehicle emission regulation (see the Case Studies chapter for a detailed description of the Auto-Oil programme). The programme's guiding principle has been for the European Commission, the motor and oil industries and, more recently, other related industries, NGOs and research institutes, to address road vehicle emissions more holistically than previously. Participants would pool their information and subsequently design a framework to assess contributions from measures to meet future urban air quality standards.

It should be beneficial for funding organisations to consider encouraging private participation in the policy process. The success of such an arrangement is likely to be determined by whether the agreement between the particular funding organisation and the individual country governments makes explicit the need for full stakeholder participation in the policy design process and, where appropriate, makes this a condition of the policy/project lending. Other determinants are captures in the following strictures that have been compiled in this regard:

- Responsibility for the implementation of the end policy should be clearly defined throughout the policy design process. As a result, the incentive to achieve greenhouse gas emission targets will be upheld over the lifetime of the policy.

- The policy design process should be clearly informed by the need to produce a policy outcome that meets the criteria of economic efficiency. Thus, the relatively high resource intensity that the participative process demands will be compatible with cost-effective criteria.

- As far as possible, the dates for emission targets should be agreed upon at the earliest possible time. This will ensure that industry can plan production developments with some degree of certainty. The technical requirements, however, will be decided during the course of the programme.

- Synergies with existing programmes should be exploited in order to ensure that wider country coverage in priority regions is facilitated.

10.6 Concluding Comments

It is clear from the experience of public-private sector collaboration reviewed in this chapter that funding organisations can take advantage of the wide variety of mechanisms that already exist at national and international levels. Opportunities for private sector collaboration in GHG reduction inclusive programmes can therefore be encouraged in the most cost-effective manner. Introducing new mechanisms could be easier if funding organisations exploit networks of private sector producers maintained by international industry associations. The following chapter presents some case studies of public-private sector collaboration.

11. Private Sector Collaboration: Case Studies

11.1 Introduction

This section describes two cases of public-private collaboration: California Air Resources Board (CARB)'s Low-Emissions Vehicle (LEV) Programme, and Europe's Auto-Oil programme.

CARB passed the LEV mandate to accelerate development and deployment of Zero-Emission Vehicle (ZEV) and other low emission vehicle technologies. This case study discusses possible impacts of the ZEV mandate on energy consumption and carbon dioxide emissions in California and illustrates a regulatory approach featuring extensive negotiation between vehicle manufacturers and regulators. The ZEV mandate appeared at first to be effective in introducing electric cars to market- though increasingly parties recognised this as not commercially viable. This approach has come to be seen as inflexible, inefficient and warns against such a stringent approach elsewhere.

The Auto-Oil Case Study reports recent European vehicle emissions regulation. This is relevant to private sector collaboration in a GHG reduction inclusive programme because the EU Auto-Oil programme interests include the vehicle manufacturing industry, the oil industry and NGOs in a cost-effectiveness framework policymaking process.

11.2 Carbon dioxide implications of the California Zero-Emission vehicle programme

This case study discusses impacts of the Zero-Emission Vehicle (ZEV) mandate on energy consumption and carbon dioxide emissions in California, through cost and energy comparisons with conventional vehicles. The California Air Resources Board (CARB) adopted the broader Low-Emissions Vehicle (LEV) Programme on September 28, 1990. The Programme has three parts: reduced emissions standards; ability of vehicle suppliers to average, "bank", and trade emissions; (ZEV) mandate, the subject of this study. CARB passed the mandate to accelerate development and deployment of ZEV technologies, in order to acquire air-quality benefits.

History and Context: A growing vehicle fleet, increasing population, and increasing miles being driven have contributed to California's increased automobile emissions. Conventional gasoline and diesel-powered vehicles currently emit more than 60% of all pollutants that contribute to ozone and particulate matter air pollution in California (CARB A, 1999). Air quality is the principal factor pushing electric vehicle development. A Zero-Emissions Vehicle produces no tailpipe emissions, no evaporative emissions, no emissions from gasoline refining or sales, and has no on-board emission control systems to deteriorate over time. ZEVs reduce carbon dioxide emissions and emissions of toxic air contaminants such as benzene and 1,3- butadiene (CARB A, 1999). The only technology able to meet ZEV requirements is the electric vehicle, however, it is likely that fuel cells and hybrid vehicles may qualify as ZEVs in the near future. Originally, the ZEV mandate required that the seven largest auto manufacturers, (those selling more than 35,000 vehicles each year in California,) sell

2% ZEV in 1998-2000, 5% ZEV in 2001-2002, and 10% ZEV in 2003 and beyond. Since then, CARB has retracted the mandate's deadlines, except for the 2003 requirement.

The CARB entered into a memorandum of agreement, outside of the LEV programme, with the seven largest auto manufacturers (CARB C, 1999) giving both government and manufacturers greater flexibility in meeting the ZEV requirements. The auto manufacturers agreed to continue investment in ZEV and battery R&D, marketing up to 3,750 advanced battery-powered ZEVs in 1998, 1999 and 2000, and issuing regular reports to the CARB. They also agreed to offset the emissions benefits lost due to the elimination of the 1998 through 2002 ZEV requirements by joining the National Low-Emission Vehicle programme in 2001. Finally, manufacturers agreed to "participate in a market-based ZEV launch by offering ZEVs to consumers in accordance with market demand" (CARB C, 1999). The CARB has agreed to facilitate the purchase of ZEVs in state fleets, to work with other state agencies, local governments, and private industries to address infrastructure issues, to create an emergency response training programme, and to support incentive programmes (CARB C, 1999). Failure to comply would result in fines and possible reinstatement of the ZEV requirements prior to 2003. If a manufacturer does not meet the 10% requirement in 2003, each ZEV car not produced, up to 10% of the fleet, will result in a $5,000 fine (Sperling, 1995).

However, vehicle manufacturers fear that consumer desire for ZEVs is negligible. In the early 19902, the Ford Motor Company predicted that only one percent of Americans would buy electric vehicles (Sperling, 1995). Automakers worry that current battery technology is not commercially viable (Sperling, 1995). Electric cars will be expensive, with limited driving range, and manufacturers state that they would raise prices on conventional models to compensate. Manufacturers worry about the viability of developing an entirely new vehicle concept. A viable electric vehicle needs a substantial redesign, new materials and parts, not a simple modification of existing technologies and methodologies. A redesigned car would also require a redesigned support infrastructure, all of which concern manufacturers.

Costs: The ZEV mandate has resulted in major investments in electric vehicle technology in the 1990s (Sperling, 1995). While the mandate has stimulated this investment, ZEVs are still a new technology produced in very limited quantities, making them much more expensive than conventional, mass-produced vehicles. Prices are likely to decline once economies of scale come into effect and ZEV technology is widespread, however, it is unlikely that the initial purchase price will be comparable to that of gasoline and diesel powered vehicles in the near future. Comparing life-cycle costs, however, ZEVs and conventional vehicles may be very similar (Table 11.1). In the meantime, there are a number of federal, state, local, and private incentive programmes offering tax credits, funding assistance, rebates and utility discounts (CARB B, 1999).

Table 11.1 Costs of subcompact electric cars versus gasoline-powered cars

		Near term		Medium term		Long term	
	Gasoline	Low	High	Low	High	Low	High
Battery	----	Lead acid		Nickel-metal hydride		Lithium sulphide	
Range (miles)	300	100	100	75	125	100	200
Purchase cost with battery ($)	12,944	17,761	27,775	15,769	21,124	15,685	18,916
Cents/mile	26.7	29.9	36.8	25.8	33.0	27.8	29.9

Source: Sperling, 1995
Note: The three scenarios incorporate and are based upon near-term advanced lead-acid batteries and the mid-term and long-term battery goals established by the U.S. Advanced Battery Consortium.

Table 11.1 shows that ZEV and gasoline vehicle life-cycle costs are comparable, although ZEVs range is much less than gasoline vehicle range. Gasoline vehicles generally cost about 26.7 cents per mile driven, while electric vehicles are expected to cost between 25.8 and 36.8 cents per mile. Generally, electric vehicles will have lower operating costs and a longer vehicle life than gasoline cars. Improving battery technology may modify the table results, as will driving conditions. Electric vehicles are more energy efficient than gasoline cars at speeds under 20 miles per hour, and less efficient at speeds greater than 50 miles per hour. Costs will also shift depending on the price of electricity for ZEV users.

Global and Local Emissions: While overall costs for ZEVs and gasoline vehicles are similar, their emissions vary considerably. Automobiles and light trucks currently contribute about half of all urban air pollution in California. Much of the difference in emissions depends on how electricity to charge ZEVs is generated.

According to Table 11.2, proliferation of ZEVs would reduce hydrocarbons, carbon monoxide, and nitrogen oxide emissions, while sulphur oxides and particulate matter might increase substantially. The impact of this increase is low proportionally, as current vehicles produce almost all human-produced carbon monoxide, about half the hydrocarbon and nitrogen oxide pollutants, and only about 1 percent of sulphur oxide and particulate matter pollutants (Sperling, 1995). These percentages vary by country depending on the national mix of power generation. For example, electricity generated with natural gas would minimise sulphur dioxide emissions, while electricity generated with coal would increase these emissions. Increasing electric vehicle efficiencies and power generation will affect emissions as well. On a per-mile basis, electric vehicles powered from coal-fired power plants would increase greenhouse gas emissions slightly, while those powered from natural gas-fired power plants would decrease emissions substantially, and vehicles powered from hydro, nuclear, or solar power plants would emit almost no emissions (Table 11.3). Electric vehicle use shifts pollution from a mobile source (vehicles) to a non-mobile source (power plants). The overall effect of these changes depends, of course, on the extent the electric vehicle market penetration.

Table 11.2 Percentage change in emissions from gasoline-powered cars to battery-powered electric cars

	Hydrocarbons	Carbon monoxide	Nitrogen oxides	Sulphur oxides	Particulates
France	-99	-99	-91	-58	-59
Germany	-98	-99	-66	+96	-96
Japan	-99	-99	-66	-40	+10
United Kingdom	-98	-99	-34	+407	+165
United States	-96	-99	-67	+203	+122

Sources: Choosing an Alternative Fuel: Air Pollution and Greenhouse Gas Impacts (Paris: OECD, 1993). U.S. estimates are from Wang et al(1990).
Note: Emissions from the full fuel cycle are accounted for, including tailpipe, evaporative, and refinery emissions associated with gasoline use in cars. Emissions include those from electricity generation for battery-powered cars, based on the current fuel mix.

Table 11.3 Change in Greenhouse-Gas Emissions from Gasoline-Powered to Electric Vehicles

Electric vehicle fuel/feedstock	Change (percent)
Solar and nuclear	-90 to –80
Natural gas plants	-50 to –25
Current U.S. power mix	-20 to 0
New coal plant	0 to +10

Source: Delucchi,(1991)
Notes: Emissions from vehicle and materials manufacturing are assumed to come from fossil fuels. If these manufacturing processes were excluded, or were assumed to use non-fossil energy such as solar, then electric vehicles would provide an additional 10 percent reduction.

Summary: In summary, the spread of ZEVs require major changes in manufacturing, infrastructure, and battery technology. While more inexpensive, immediate carbon reduction options exist, ZEV potential is immense, depending on market penetration. ZEV, current gasoline, and diesel vehicle life cycle costs will be almost the same in the future, but ZEVs offer substantial greenhouse gas reduction.

As a mechanism for private sector collaboration with public funding organisations, the memorandum of agreement set up between CARB and vehicle manufacturers seems useful in promoting stakeholder involvement in decision making, and this is likely to be a valuable principal in developing GHG reduction inclusive programmes in the transportation sector. The test of its strength is likely to be whether it can bring about the phase-in of ZEVs in the vehicle market without the imposition of other policy instruments/

11.3 European Commission Auto-Oil programme Case Study

11.3.1 Introduction

A study of recent European vehicle emission regulation is particularly relevant to possible private sector collaboration within a GHG reduction inclusive policy framework, since the EU Auto-Oil programme involves vehicle manufacturers, the oil industry and NGOs in a policy making process, and uses a cost-effectiveness framework.

11.3.2 Overview of the Auto-Oil programme

The Auto Oil Programme was set up in 1993 as a collaboration between different parts of the European Commission, (the policy making bureaucracy that supports the European Union), the European Oil Industry, (EUROPIA), and the European car manufacturer association, (ACEA). The programme sought to reduce road transport emissions to levels consistent with clean air that imposes the least cost burden on Europe. The strategy and two proposals – one on fuel quality and one on car emission standards – were adopted in June 1996. Two more proposals have followed – one on vans and one on heavy-duty engines - now in the process of becoming Directives (the EU legislative instrument).

The original proposals featured fuel and car standards for the year 2000 as well as indicative car standards for 2005, though the European Parliament since has imposed both fuel and car standards for 2005. The Auto Oil II Programme is reviewing these standards. The EU programme includes all relevant industries (not only oil and car), European Union Member states, Non-Governmental Organizations (NGOs) and research institutes.

11.3.3 History of EU Vehicle Emission Regulatory Development

The trans-national nature of air pollution from vehicles has ensured that from 1957 the United Nations Economic Commission for Europe (UNECE) has considered vehicle emission regulation. During the 1970s, the European Commission used the UNECE regulations to establish directives, but imposed them on a voluntary basis.

The 1980s saw disagreement between EC member states regarding the adoption of stricter car emission limits and the introduction of unleaded fuel. European vehicle producers inexperienced in catalytic converter-fitted cars challenged EC legislation, which made catalytic converters compulsory. The legislation was controversial also because industry as a whole felt that neither proposal costs nor benefits had been assessed properly.

In 1984, the European Commission set up the Motor Vehicles Emission Group, (MVEG), which can be seen as a precursor to Auto Oil, consisting of industry experts who inform the Commission on technical issues relating to vehicle emissions.

11.3.4 The Auto Oil Programme

Made up of two chronological phases, Auto Oil I, ran from 1993 to 1997 and Auto Oil II began in 1998. In terms of private sector involvement, scope of measures and environmental effects considered, Auto Oil II is more successful. Both phases are briefly reviewed in order to illustrate the issues likely to arise when considering the adoption of such an approach.

Auto Oil I
The European Commission initiated the Auto Oil I Programme to develop a more comprehensive approach to reducing emissions from road transport. The triumvirate of the Commission, the motor industry and the oil industry would address road vehicle emissions in a more holistic way. Participants would pool information and

design a rational framework for assessing cost-effective options from a range of measures, to meet urban air quality standards.

The programme included three research areas: 1-a technical experimental research programme, the European Programme on Emissions, Fuels and Engine Technologies (EPEFE); 2-an air quality modelling study; 3-a cost-effectiveness modelling study. The EPEFE, jointly carried out by ACEA and EUROPIA focused on vehicle technology's and fuel characteristics' effect on emissions. The complexity of relationships among the three components was confirmed and key linkages defined. One such finding, for example, was that engines in different vehicle categories have opposite responses to changes in fuel properties, so that reducing polycyclics in diesel reduced HC emissions in heavy duty engines but increased HC, CO and benzene emissions in light duty vehicles. Using this research, the European Commission proposed measures involving improved vehicle technology, better fuel quality, and certain non-technical measures.

The European Parliament (EP) considered and made proposals arising from the Auto Oil I Programme more stringent. Nevertheless, the resulting limit values for petrol fuels for 2000 and 2005 placed the burden of stringency on the vehicle manufacturers through emission standards rather than on the oil industry through fuel quality standards.

Auto Oil II
The Auto Oil II Programme began in late 1997, and was intended to review the Commission proposals for limit values for 2005 as well as further developing the methodology from the first phase. The remit has been reduced by the inclusion of mandatory standards for the year 2005 in the first round of legislation. Auto Oil II has built on Auto Oil I's organisational structure by including more stakeholders and covering more issues.

The European Commission presented the draft work programme to the stakeholders for discussion before establishing working groups with individual terms of reference. Each group includes experts nominated by stakeholders, chaired by a Commission official and co-coordinated by the Commission's Ad Hoc Management Group, who report to a contact group. The contact group, which meets three or four times per year, includes representatives of relevant industry associations and NGOs, chaired by the Commission. It serves as a forum where interest may discuss issues of general interest, and receive and comment on interim reports and progress reports from the working groups.

Auto Oil II's scope is broader and many of the criticisms of Auto Oil I are addressed:

- Representatives of member states and NGOs are now included in the Programme;
- A stationary source pollution inventory is included to attempt a cross-optimisation of emission reductions from different sectors;
- Effects of proposed measures on CO_2 emissions are considered;
- Analysis of cost-effectiveness beyond the year 2010 is being undertaken;

- Consideration is given to the possibility that economic policy instruments such as taxes and tradable permit schemes could contribute to the cost-effectiveness of air quality targets;
- Inclusion of new refinery and propulsion technologies to produce cost effective measures for considering integrated refinery-vehicle-fuel systems process as a whole;
- Measures resulting from cost-effectiveness analysis will be related to the Ambient Air Quality Framework Directive, and directives taking account of cost-benefit analysis.

11.3.5 Rationale, and Mechanisms for Ensuring Private Sector Inclusion

The value of the Auto Oil Programme's technical research has been high, furthering the current state of knowledge. However, involved parties have skewed using this research in policy formulation. For example, the favourable outcome of Auto Oil I resulted to some degree from the considerable staff and financial resources applied by the oil industry representatives in the forum. The degree of participation is therefore clearly determined by the scale of resources available to the individual party. However, private sector collaboration is likely to have more credibility in a participatory sense if all stakeholders are encouraged and supported in their involvement in GHG reduction inclusive programmes at local, national or regional levels

An issue that has arisen from the participatory process in the Auto Oil programme is the responsibility for policy outcome. Peake (1997) states that " …the multi-faceted approach involving international government, national governments and several layers of sub-government, and two major industries, (in policy design and implementation), has probably done more to cloud the issue of who takes ultimate long term responsibility for achieving air quality standards, or where the blame may lie in case of non-attainment in the years to come." This cloudiness is inevitable to some extent in a multi-tier process where policy resolution and enforcement are undertaken by separate organisations. Funding organisations therefore need to ensure that all parties know who bears responsibility for agreed-upon policy. Responsibility is then explicit at the outset of the policy process.

11.3.6 Private Sector Involvement in the Auto Oil programme: Form and Scope

The Auto Oil programme might be resource-intensive, compared to a more traditional policy process, so Phase I's outcome generally is regarded to be inadequate in terms of improved environmental quality. This is ascribed to effective lobbying by the oil industry, so it is unclear whether the first phase of the programme was an **efficient** means of reaching the outcome, or, indeed **fair,** given that the outcome favoured the party devoting most resources to the process.

This experience indicates a more general criticism made about this type of private sector collaboration – namely that industrial representatives are not likely to agree to any regulatory proposal that is harmful to their commercial interests. As a result, more demanding, economically efficient regulatory outcomes will not be possible.

To counteract these concerns, any GHG reduction inclusive programme must be aware that participation needs to be full and represent all stakeholders to reduce the likelihood that the efficiency and effectiveness of the environmental outcome is not sacrificed through partial participation. In addition, this form of private sector collaboration must be assessed for its likely heavy resource intensity. In other words, as well as the democratic advantages of greater participation, attention needs to be paid to the "value for money."

11.3.7 Determining Time Scales for Negotiation and Policy Implementation

There are two possible conclusions about the relatively long lead-times between legislative proposal and implementation in the Auto Oil programme. Peake (1997) comments that "on the one hand, industry has long called for greater lead times and more certainty about future standards. On the other hand, the nature of air quality and cost effectiveness driven programmes is that the basis of analysis necessarily dates rapidly as new information about real trends in air quality, technological developments and cost functions change data".

In promoting a similar policy, therefore, it is important the funding organisations recognise that the lead-time between the production of policy proposals that impact on industry should be agreed as far as possible at the outset of the collaboration. There should, however, be a proviso for circumstances when the environmental quality turns out to be drastically different from that initially expected.

11.3.8 Outcome Efficiency

Policy cost effectiveness will only be realised if an inter-sectoral approach is adopted – an approach neglected until recently in the European Auto-Oil programme. The programme needs to include an economy-wide analysis of mitigation costs to ensure that least cost measures are exploited first within an overall mitigation strategy.

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Annex I: Glossary

Abatement cost curve
These curves express the relationship between the minimum cost to society of reducing an additional tonne of GHG and the corresponding level of emission reduction. Abatement cost curves rise to the right, since increasing levels of abatement can be achieved at greatest unit costs.

Additional cost/expenditure
This term refers to the difference between **all** costs incurred under the *Baseline case*, which may be defined by either the *Business-as-Usual case* or the *Transport Reform case*, and all costs incurred under the *Mitigation policy* case.

Annual capital cost
An equal, or uniform, payment made over the useful life of a *project*, which has the same *present value* as the initial *investment expenditure*. The annual capital cost of an asset essentially reflects the *opportunity cost* to the investor of owning the asset.

Annual capital costs are equal to the initial *investment expenditure* multiplied by an appropriate *capital recovery factor*. Equally, annual capital costs may be approximated as the sum of an annual *depreciation charge* and the time-adjusted average interest charge on the unpaid balance.

Average cost
The total cost of supplying a given output, divided by the number of units of output delivered in a given period of time. Where there are multiple outputs, the issue of adding them up has to be addressed (see *joint costs*, below).

Avoided costs
The value of any savings in labour, energy or materials inputs, relative to the *base case*, resulting from operating the *project*.

Base year
In the context of processing time-dependent data such as costs or emissions, the base year is the year selected for assembly of the raw input data. The base year may also serve as the year from which projections of the *base case* are made.

Capital recovery factor
A factor used to calculate the *annual capital costs* of an *project*. A capital recovery factor may equally be used to determine the *equivalent annual cost* of the stream of annual cash outflows (i.e. the initial *investment expenditure* and the series of "net" annual *operating and maintenance costs*) incurred over the useful life of an project.

Constant prices
See *real prices.*

Current prices
See *nominal prices*.

Deflation
A decrease in the *general price level* or an increase in the *purchasing power* of money.

Depreciation charge
Capital goods (e.g. installed pollution abatement equipment) are typically used up over a period of time. Each year, a portion of the usefulness of these assets expires, therefore a portion of the original *investment expenditure* should be recognised as an annual (capital) cost. The term depreciation refers to the systematic allocation of the cost of an asset to expense over the accounting periods making up its useful life.

Direct costs
Direct costs refer to those costs that can be primarily attributed to the *project*. That is, direct costs measure the value of the additional resources used to purchase, install, operate and maintain the project.

Discounted (cash flow) net benefit
The *present value* of expected future *net benefits*.

Discount factor
The *present value* of a single unit of currency received in the future (normally one year from now). If the discount rate is r, then the discount factor is $1/(1+r)$.

Discount rate
The rate used to discount future *net benefits* to their *present value*.

Discounting
The process of determining the *present value* of future *net benefits*.

Economic cost
The cost associated with the supply of any good or service, measured in terms of opportunity costs of the inputs used.

Economic life
The time at which the marginal costs of operating and maintaining an *project* exceed the marginal benefits provided by the asset - because other factors, such as technological change or changes in economic circumstances, may render the asset obsolete or inadequate. The economic life of an project may differ from its *technical life*; the economic life is typically shorter than the technical life.

Equivalent annual cost
An equal, or uniform, payment made over the useful life of an *project*, which has the same *present value* as the stream of annual cash outflows (i.e. the initial *investment expenditure* plus the series of net annual *operating and maintenance costs*) associated with the measure.

Exchange Rate
The exchange rate for foreign currency is the price of a unit of the foreign currency in terms of the domestic currency.

External cost
The costs arising from the provision of any good or service that are not taken into account by the provider of that good or service when making decisions about methods of production and level of production.

Financial cost
Those money payments associated with any given set of economic costs.

General price level
The weighted average price of all goods and services in the economy, relative to their prices at some fixed date in the past. The general price level shows what is happening to prices on average, not what is happening to the prices of individual goods. Increases in the price of specific goods and services does not necessarily imply that the average price level has changed. For example, increases in the price of gasoline may be offset by decreases in the price of electricity, in which case, the average price level will thus remain constant. For the average price level to move upward, the prices of a majority of commodities traded in an economy have to increase. Changes in the general price level are measured by the consumer *price index* with a *base year* assigned a value of 100.

Generalized cost
The total cost an individual pays to make use of a mode of transport, including the "out-of-pocket" cost – i.e. the market price of making the trip – the value of time taken and any other non-monetary factors incurred in making the trip.

Global pollutants
Those pollutants which cause damage that is evident worldwide (e.g. climate change). The greenhouse gases, which include carbon dioxide, methane, nitrous oxide, tropospheric ozone and CFCs, are one type of global pollutants.

Greenhouse effect
The absorption of outgoing infra-red radiation by greenhouse gases and water vapor, which thereby raises the Earth's temperature.

Hydrocarbons
Compounds composed primarily of hydrogen and carbon.

Indirect costs
Indirect costs refer to those costs associated with changes in demand in related (markets) sectors of the economy through backward and forward production linkages with the *project*. For example, the (direct) expenditures on an project may induce changes in demand for certain resources and related services throughout the economy. The net value of these induced changes is an indirect cost of investing in the project.

Inflation
An increase in the *general price level* or a decrease in the *purchasing power* of money.

Interest cost (charge)
A charge made for the use of money. The yearly interest charge on the unpaid capital balance is one part of the *annual capital cost*.

Interest rate
The ratio of the interest charged in any one time period to the original *investment expenditure*.

Investment expenditure
The total expenditure made in a given year to purchase plant/equipment or other infrastructure items from a supplier, and all expenditures associated with installing these items and making it operational. This includes the purchase of land, general site preparation etc., if required.

Investment expenditure is distinct from the capital cost of an *project*. Capital goods provide services over a number of years and therefore only a portion of the original investment expenditure is recognised as an annual (capital) cost. In contrast, investment expenditure indicates the total value of the capital good in the year of acquisition and thus does not reflect the use of the asset over time.

Joint cost
The costs associated with the provision of more than one type of output. Frequently a project delivers more than one final product. Some of the costs can be clearly attributed to each separate product, but some costs are shared. These shared costs are joint costs. Rules of attributing them exist (e.g. on the basis of the relative value of final output, or on the basis of the value of relative value of some variable input), but these are essentially arbitrary.

Levelised cost
The costs of any project comprise capital costs and variable costs. The capital costs are shared by the production that takes place over a number of years. The levelised costs is a constant annual cost that is equivalent in present value terms to the actual capital and variable costs of the project.

Local pollutants
The impact of these pollutants is evident in the vicinity of the emission. Local pollutants, which may also be *regional pollutants*, include sulphur dioxide, lead, particulate matter, nitrogen oxides, carbon monoxide and tropospheric ozone.

Marginal cost
The additional costs incurred when production is increased by a small amount. Cost increases are not 'smooth' in all cases, however. When existing capacity is adequate, the marginal cost is simply the additional variable cost. When capacity is fully used, the marginal cost includes the additional capacity cost. Normally marginal costs are calculated to include capacity cost, for an increase in output that fully uses that additional capacity.

Mitigation inclusive policies
Policy objectives for a project, sector or economy that include GHG externalities as a policy objective.

Mitigation costs
The additional costs of reducing GHG emissions associated with a transportation programme compared with the cost of a similar transportation programme with higher associated GHG emissions. The additional cost can be related to the incremental GHG emission reduction.

Mitigation benefits
The benefits are given by the difference in GHG emissions associated with a mitigation inclusive transportation programme compared with the GHG emissions associated with a programme without the mitigation objective.

Nominal (Current) prices
Nominal or current price variables refer to values at the prices ruling when the variable was measured. Such prices have not been adjusted for the effects of *inflation*.

Nominal discount/interest rate
Nominal or current price variables refer to values at the prices ruling when the variable was measured. Such prices have not been adjusted for the effects of *inflation*.

Non-recurring costs
See *investment expenditure*.

No-regrets measures
A project or policy intervention which achieves its stated objective at no incremental cost.

Operating and maintenance costs
The cost of the energy, labour, materials and environmental services required to operate and maintain the *project* during a single year. Operating and maintenance costs may include fixed annual costs associated with administration, insurance premiums and other general overheads. However, they exclude any costs associated with the financing and depreciation of plant or equipment. These are covered through the use of a *capital recovery factor* when determining *total annual costs* or *annual capital costs*.

As operating and maintenance costs are incurred annually throughout the useful life of the project, they are also known as recurring costs.

Opportunity cost
The value of a scarce resource in its next best alternative use. The economic, or 'true' private, cost of a resource is given by its opportunity cost.

Opportunity cost of capital
The expected rate of return that is foregone by investing in the *project* rather than in the best alternative investment.

Present value
The amount of money today considered equivalent to a cash inflow or outflow expected to take place in the future. That is, the discounted value of future cash flows.

Price deflator
A price indicator used to convert (to deflate) between *nominal* and *real* prices. The Gross Domestic Product (GDP) deflator at market prices is an example of such a price indicator. The GDP market prices deflator provides an index of inflation in the economy as a whole, and therefore is equally applicable in removing the effects of inflation from industrial and domestic prices.

Price index
Index numbers, which have no units, are values expressed as a percentage of a single base figure. For example, if the average current price of heavy fuel oil (HFO) was Euro 104.4 per tonne and Euro 115.3 per tonne in 1995 and 1996 respectively, the price in 1996 was 110 per cent of that in 1995. In index terms, the average price of HFO in 1995 and 1996 was 100 and 110 respectively. This is an example of a *current* price index. Price indices can just as easily be expressed in *real* terms by making the appropriate adjustments for *inflation*.

Primary pollutant
A (chemical) contaminant emitted directly to the atmosphere by a emission source.

Private cost
The costs taken into account by identifiable parties in making production and supply decisions.

Purchasing power
The ability of money to buy goods and services. As the *general price level* rises, the purchasing power of money declines. Thus, in periods of *inflation*, an ever increasing amount of money is required to represent a given amount of purchasing power.

Real (constant) prices
Real or constant price variables adjust *nominal* variables for changes in the general level of prices. They are inflation-adjusted prices.

Real discount/interest rate
A *nominal* discount/interest rate adjusted for *inflation* so that it represents an increase in purchasing power. The real discount/interest rate measures how much extra consumption you can have in period 2 if you give up some consumption in period 1.

Recurring costs
See *operating and maintenance costs*.

Regional pollutants
The impact of these pollutants is evident at significant distance from the emission source. Regional pollutants, which may also be *local pollutants*, include sulphur oxides, nitrogen oxides and tropospheric ozone.

Relative prices

The price of a particular good or service relative to other goods and services in general. If any good or service is expected to change relative to the *general price level*, then it is said to have changed in *real* terms.

Secondary costs/benefits

Costs or benefits arising from a productive activity that are not the **main** focus of that activity. Given this definition, there is clearly an element of arbitrariness in the definition of what is secondary. Where such costs/benefits exist, they give rise to the allocation of joint costs – those production costs that have to be shared between the main output and the secondary output.

Secondary pollutant

A (chemical) contaminant formed, from *primary pollutants*, by chemical processes in the atmosphere.

Social costs

The sum of the private and the external costs of any given activity are defined as the social costs.

Technical life

The estimated "physical" life of an *projects*, i.e. the time at which the asset literally wears out due to "physical" deterioration. The estimated technical life of an *project* is a function of the assumed maintenance regime; a good repair policy may lengthen the life of the asset.

Time preference

Refers to the preference of an individual or society for current consumption versus future consumption. For example, if an additional unit of consumption in any one year has the same social value as 1.10 additional units of consumption in the following year, then the marginal time preference rate (or implied social discount rate) is 10 per cent.

Total annual cost

See *levelised costs.*

Total cost

This is an imprecise term, which is used to refer to the sum of the capital and variable costs (with or without discounting), the sum of the external and private costs etc. Without further qualification it has little meaning.

Win-win measures

See *no-regrets measures.*

Annex II: Illustration of total annual cost and cost-effectiveness calculations

Calculating annual costs

The two main approaches for computing total annual costs presented below are based on the following data set:

Investment expenditures:	$250,000
Infrastructure	$187,500
Equipment	$62,500
Net recurring costs:	
Energy	$20,000
Labour	$50,000
Materials	$5,000
Offsetting benefits	$0
Equipment lifetime	5 years
Appropriate interest rate	8%

For simplicity, it is assumed that the capital goods have no resale or salvage value.

Approach 1 - Depreciation plus interest calculation
With this approach the annual cost of the project is obtained by summing the yearly capital and net recurring costs. The capital cost in each year is made up of a **depreciation charge** and the **interest cost** on the outstanding capital balance.

Depreciation charge
The simplest method for depreciating the capital goods is the straight-line method. This method assumes that these goods contribute their services equally to each year's operation so that the total investment expenditure is evenly allocated over the lifetime of the equipment. Thus the yearly depreciation expense is a constant given by:

$$R_t = \frac{W}{n}$$

where R_t is the depreciation charge in year t, W is the depreciation base of the equipment, i.e. the difference between the original cost of the capital goods (C_0) and the salvage value (S_n), and n is the estimated useful lifetime of the equipment in years (or write-off period).

The accumulated depreciation D_t at the end of year t is then given by

$$D_t = t\, R_t .$$

The book value B_t of the equipment, i.e. the unamortised portion, at the end of year t is

$$B_t = C_0 - t\, R_t .$$

Using the straight-line method, the depreciation schedule for the capital goods is given below.

Depreciation charge: Straight-line method

End of year	Yearly depreciation charge	Accumulated depreciation	Book value
(t)	R_t	D_t	B_t
0	-	-	$250,000
1	$50,000	$50,000	$200,000
2	$50,000	$100,000	$150,000
3	$50,000	$150,000	$100,000
4	$50,000	$200,000	$50,000
5	$50,000	$250,000	-

Interest cost
In purchasing the capital goods, $250,000 is essentially being tied up. If these funds were not invested in the new equipment, they could be invested either in something else which will earn a return, or, if there are loans which are repayable, this indebtedness can be reduced and the interest cost saved. An annual interest cost should, therefore, be included in the annual cost calculation.

It is incorrect however, to compute the annual interest cost as 8 per cent of $250,000 (i.e. $20,000), as the investment is being reduced each year by the depreciation-recovery charge of $50,000. The $20,000 is the valid interest charge in the first year only. In general terms, the average interest cost per year is given by

$$\text{average interest cost per year} = \frac{1}{2}\left(C_0\, r + \frac{C_0\, r}{n} \right)$$

where r is the interest rate per period. In this case, the average yearly interest cost is $12,000. This is the appropriate amount to use in the annual cost calculations.

The annual capital cost of the capital goods is therefore equal to $62,000; that is, the sum of the average yearly depreciation charge ($50,000) and the average yearly interest cost ($12,000). To this the net annual recurring costs must be added to

determine the total annual cost of the project. Hence, the total annual cost of the project should read

Annual capital cost:

Yearly depreciation charge	+$50,000	
Interest cost per year	+$12,000	
Sub-total	=	+$62,000
Net recurring costs:		
Energy	+$20,000	
Labour	+$50,000	
Materials	+$5,000	
Offsetting benefits	-$0	
Sub-total	=	+$75,000
Total annual cost		=$137,000

Expressed in general terms, the total annual cost of a project or policy intervention, using the 'depreciation plus interest' approach, is given by

$$\text{total annual cost} = \frac{(C_0 - S_n)}{n} + \frac{1}{2}\left(C_0\,r + \frac{C_0\,r}{n}\right) + RC$$

where RC is the 'average' net annual recurring costs.

Approach 2. discounted cash flow approach
An alternative to the above approach, and one which offers greater flexibility, involves first determining the present value total cost of the project, and then applying a capital recovery factor. The present value total cost (PVC) of an investment is computed as follows:

$$PVC = \sum_{t=0}^{n} \frac{(C_t + RC_t)}{(1+r)^t}.$$

The present value of the total cost stream of the project is $549,500; the calculations are summarised in the table below. This represents the total cost to be recovered in equal annual amounts (denoted by A_t) over the lifetime of the equipment. Therefore, the total annual cost of the project is given by:

$$A_t = PVC\left[\frac{r(1+r)^n}{(1+r)^n - 1}\right] = \$549,500\left[\frac{0.08(1.08)^5}{(1.08)^5 - 1}\right] = \$549,500\,(0.2505) = \$137,600$$

The second term in the brackets is the **capital recovery factor**. This approach offers greater flexibility in that it provides a framework for explicitly considering, for example, the effects of price escalation on the various recurring cost components.

In this example, the $137,600 total annual cost is not significantly different from the $137,000 cost calculated through the depreciation plus average interest approach.

Present value calculation

Year	0	1	2	3	4	5
1 **Discount factor**	1.000	0.9259	0.8573	0.7938	0.7350	0.6806
2 **Investment expend.** (a+b):	$250,000	-	-	-	-	-
a Infrastructure	$187,500	-	-	-	-	-
b Equipment	$62,500	-	-	-	-	-
3 **Recurring costs** (a+b+c-d):	-	$75,000	$75,000	$75,000	$75,000	$75,000
a Energy	-	$20,000	$20,000	$20,000	$20,000	$20,000
b Labour	-	$50,000	$50,000	$50,000	$50,000	$50,000
c Materials	-	$5,000	$5,000	$5,000	$5,000	$5,000
d Offsetting benefits	-	-	-	-	-	-
4 **Total cost** (1+3)	$250,000	$75,000	$75,000	$75,000	$75,000	$75,000
5 **Discounted total cost** (1*4)	$250,000	$69,443	$64,298	$59,535	$55,125	$51,045
6 **PVC** (sum line 5)	$549,446					

Expressed in general terms, the total annual cost of a project or policy intervention may be calculated with the use of a capital recovery factor in one of two ways:

$$\text{total annual cost} = \left[\sum_{t=0}^{n} \frac{(C_t + RC_t)}{(1+r)^t} \right] \left[\frac{r(1+r)^n}{(1+r)^n - 1} \right] \text{ or}$$

$$\text{total annual cost} = C_o \left[\frac{r(1+r)^n}{(1+r)^n - 1} \right] + RC .$$

The latter way is appropriate if the annual recurring costs are constant over the life of the project.

Measures of cost-effectiveness

The cost-effectiveness of a project or policy intervention in delivering a given output may be assessed in one of two ways: one approach is based on the concept of **net present value**; the second approach is based on the concept of **levelised cost**. Using the output of the total annual cost calculations, we will illustrate how these two approaches are used to estimate the cost-effectiveness of the project.

Approach 1. The net present value approach
Under this approach, the cost-effectiveness a project in delivering a given output (which we denote by AC) is formally given by:

$$AC = \frac{\sum_{t=0}^{n} (C_t + RC_t) \cdot (1+r)^{-t}}{\sum_{t=0}^{n} (E_t) \cdot (1+r)^{-t}}$$

where E_t is the unit output (e.g. emission reduction) in year t, and all other notation is the same as that used above. The denominator is commonly referred to as the **present tonnes equivalent** (PTE). If the project abates, say, 50 tonnes of CO_2 eq. per year, the PTE is therefore 200 tonnes of CO_2 eq. We know from above that the present value of the total cost stream of the project is \$549,500. Hence, the cost-effectiveness of the project in reducing CO_2 eq. emissions is given by:

$$AC = \frac{\sum_{t=0}^{5}(\$250,000+\$75,000)\cdot(1.08)^{-5}}{\sum_{t=0}^{5}(50 \text{ t } CO_2 \text{ eq})\cdot(1.08)^{-5}} = \frac{\$549,500}{200 \text{ t } CO_2 \text{ eq}} = \$2,750/\text{t } CO_2 \text{ eq}.$$

Approach 2. The levelised cost approach
Under this approach, the cost-effectiveness a project in delivering a given output (which we denote by AC) is formally given by:

$$AC = \frac{\left[\sum_{t=0}^{n}\frac{(C_t+RC_t)}{(1+r)^t}\right]\left[\frac{r(1+r)^n}{(1+r)^n-1}\right]}{E_t} \text{ or } \frac{C_0\left[\frac{r(1+r)^n}{(1+r)^n-1}\right]+RC_t}{E_t}$$

where all notation is the same as that used above. Recall that the numerator is simply the total annual cost.

Previously we calculated the total annual cost of the project as \$137,600. Given that the project abates 50 tonnes of CO_2 eq. per year, the cost-effectiveness of the project in reducing CO_2 eq. emissions is given by:

$$AC = \frac{\$250,000\left[\frac{0.08(1.08)^5}{(1.08)^5-1}\right]+\$75,000}{50 \text{ t } CO_2 \text{ eq}} = \frac{\$137,600}{50 \text{ t } CO_2 \text{ eq}} = \$2,750/\text{t } CO_2 \text{ eq}.$$

In this example, the two approaches produce the same estimate of AC.