ADB

Evaluation Study

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Reducing Carbon Emissions from Transport Projects

Independent Evaluation Department

Asian Development Bank

ABBREVIATIONS

ADB	–	Asian Development Bank
APTA	–	American Public Transportation Association
ASIF	–	activity–structure–intensity–fuel
BMRC	–	Bangalore Metro Rail Corporation
BRT	–	bus rapid transit
CO_2	–	carbon dioxide
COPERT	–	Computer Programme to Calculate Emissions from Road Transport
DIESEL	–	Developing Integrated Emissions Strategies for Existing Land Transport
DMC	–	developing member country
EIRR	–	economic internal rate of return
EKB	–	evaluation knowledge brief
g	–	grams
GEF	–	Global Environment Facility
GHG	–	greenhouse gas
HCV	–	heavy commercial vehicle
IEA	–	International Energy Agency
IED	–	Independent Evaluation Department
IPCC	–	Intergovernmental Panel on Climate Change
kg/l	–	kilogram per liter
km	–	kilometer
kph	–	kilometer per hour
LCV	–	light commercial vehicle
LRT	–	light rail transit
m	–	meter
MJ	–	megajoule
MMUTIS	–	Metro Manila Urban Transportation Integration Study
MRT	–	metro rail transit
NAMA	–	nationally appropriate mitigation actions
NH	–	national highway
NHDP	–	National Highway Development Project
NMT	–	nonmotorized transport
NO_x	–	nitrogen oxide
NPV	–	net present value
PCR	–	project completion report
PCU	–	passenger car unit
PRC	–	People’s Republic of China
SES	–	special evaluation study
TA	–	technical assistance
TEEMP	–	transport emissions evaluation model for projects
UNFCCC	–	United Nations Framework Convention on Climate Change
USA	–	United States of America
V–C	–	volume to capacity
VKT	–	vehicle kilometer of travel
VOC	–	vehicle operating cost

NOTE

In this report, "$" refers to US dollars.

Key Words

adb, asian development bank, greenhouse gas, carbon emissions, transport, emission saving, carbon footprint, adb transport sector operation, induced traffic, carbon dioxide emissions, vehicles, roads, mrt, metro transport

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The guidelines formally adopted by the Independent Evaluation Department (IED) on avoiding conflict of interest in its independent evaluations were observed in preparing this report. M. Replogle of Institute of Transportation & Development Policy; S. Gota of Clean Air Initiative for Asian Cities; R. Hickman, Halcrow Group Limited; and A.L. Abatayo were the consultants. The report has been reviewed by H. Dalkmann of TRL Transport Research Laboratory, United Kingdom. To the knowledge of the management of IED, the persons preparing, reviewing, or approving this report had no conflict of interest.

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EXECUTIVE SUMMARY

Economic development is required for poverty reduction. At the same time, development could also lead to increased greenhouse gas (GHG) pollution caused by the resulting growth in vehicular traffic, energy use, and other activities. GHG pollution and local air pollution threaten to undermine development with the increasing evidence of their adverse environment and health impacts. The Asian Development Bank (ADB)—with new policies supporting sustainable, low carbon growth across Asia and the Pacific—is therefore challenged to support its members in addressing these intertwined issues.

Transportation is the fastest growing major contributor to global climate change, accounting for 23% of energy-related carbon dioxide (CO_2) emissions. Many experts foresee a three- to five-fold increase in CO_2 emissions from transportation in Asian countries by 2030 compared with emissions in 2000 if no changes are made to investment strategies and policies. This is driven by the anticipated six- to eight-fold increase in the number of light-duty vehicles and a large increase in the number of trucks, which could overwhelm even the most optimistic forecasts of improvements in vehicle fuel efficiency.

ADB's Strategy 2020 envisages assistance to developing member countries (DMCs) in moving their economies onto low-carbon growth paths and to reduce the carbon footprint of Asia's cities. ADB has the opportunity to enhance its stewardship of the environment, public health, and resources by better aligning its investments with goals for climate mitigation and adaptation. This evaluation knowledge brief (EKB) provides tools and knowledge that can inform such efforts. ADB is expanding its investments in a wide array of transportation projects that are required for economic and social development, mobility, commerce, and communications. To gauge their contribution to ADB’s environmental sustainability goals, a key place to start is to better understand what aspects of ADB projects and activities contribute to or reduce transport-related CO_2 pollution. That is the central focus of this EKB, which also offers ADB tools that could be used in the future to better monitor and evaluate its carbon footprint in the transport sector. These tools may be used in conjunction with other economic analysis tools that take into account costs and benefits of specific types of transport services and their development impacts.

As the key development partner in Asia, ADB needs to explore opportunities to reduce CO_2 emissions and attract eligible funds for low carbon initiatives. Funding for land transport projects forms a substantial 96.5% of ADB’s transport sector assistance. Therefore, the EKB focuses on ADB’s assistance for land transport. Based on a study of ADB’s transport assistance approved between 2000 and 2009, this EKB develops specific models for assessing carbon emissions from various transport modes, including inter-city highways. These transport modes play a crucial role in economic development in Asia and will continue to do so. By providing a means to assess the carbon footprint of these transport projects, the EKB does not suggest diluting the development agenda in Asia. On the other hand, it suggests ways to mitigate the intensity of carbon emissions for future transport projects. In addition, ADB’s safeguards policy statement of 2009 requires the borrower/client to quantify direct GHG emissions during development or operations of the projects. By developing mechanisms to measure carbon emissions, the EKB will help ADB to support the borrower/client to meet this safeguards requirement.

Low carbon transportation strategies can be among the least costly ways to reduce GHG emissions when they are designed to reduce the need for travel, to shift trips to often less expensive low carbon modes, and to improve system management by reducing congestion and inefficiency in the use of transport capacity. These approaches can also produce disproportionate social and economic benefits for low-income people who are more dependent on walking, cycling, and public transport.

Most strategies and investments that reduce CO_2 emissions also reduce local air pollution, which imposes huge public health costs that fall disproportionately on the poor. Yet, current ADB transport project economic and environmental appraisals do not consider these elements. This EKB identifies methods and tools by which ADB could assess the CO_2 and air pollution impact of projects. It provides a first estimate of the carbon footprint of ADB transport sector assistance and the likely overall impact of ADB projects on future CO_2 emissions. It identifies the relative carbon emissions intensity of different types of ADB transport projects to CO_2 emissions and how individual projects and the overall project mix might be modified to contribute to emerging organizational, global, and national low carbon intensity growth plans, considering both costs and benefits.

Methodology

Currently, data and tools to support CO_2 impact analysis in the transport sector are inadequate to address emerging public policy analysis needs. This gap is distinctly evident in ADB's project appraisal processes. As a result, this study develops a new set of CO_2 impact analysis tools. It reviews existing global research literature on CO_2 estimation methods and factors for various transportation project types and develops a new set of CO_2 impact analysis tools. These methods and factors are synthesized and applied to data drawn from project appraisal reports, feasibility studies, and other sources for 14 projects to derive indicative CO_2 footprint and savings indicators by project type. These intensity indicators are applied to a database of ADB-supported transport projects from 2000 to 2009 to estimate the approximate overall ADB portfolio CO_2 impact. In addition, CO_2 intensity indicators are analyzed with respect to capital costs as well as passenger and freight kilometers (km) traveled. Various sensitivity tests are applied to the projects, which are examined in depth to consider how changes in assumptions, investments, or system management effectiveness might alter the estimate of CO_2 impacts.

This study is not a typical performance evaluation of past ADB projects. Instead, it evaluates the likely impact of ADB's transport portfolio on CO_2 emissions. It contributes to the development of more standardized methodologies for transport project CO_2 impact assessment and portfolio benchmarking. ADB is cooperating with other multilateral institutions and transportation stakeholders in developing and enhancing these transport project analysis tools for quick assessment of CO_2, local air pollution, and other benefits and costs.

The current tools used for this study establish the framework for developing a carbon footprint measurement mechanism for ADB transport projects. The initial set of sketch models relies on numerous assumptions about the elasticity of travel demand with respect to supply and price and the characteristics of travel markets if projects are built versus what would happen had the project not been built or if a different type of investment had been made. This study has explored the sensitivity of major findings to different assumptions. The study has its limitations. Some data (such as the inputs for assessing CO_2 emissions of railway projects) have not been sufficiently documented in either ADB project appraisals or the research literature. Where such data is found lacking for important factors, the EKB adopts reasonable assumptions for the sensitivity analysis. The lack of data has limited the sample size of the projects analyzed in detail by the EKB. Although the EKB has developed tools for estimating particulate air pollution, this has not been incorporated into the study owing to constraints on the data currently available.

Key Findings

ADB's transport portfolio CO_2 impacts can be estimated in several ways. Gross CO_2 emissions from the construction and operations of ADB-funded transport projects were estimated at 792 million tons, or an average of 39.6 million tons annually, which is comparable to the current annual land transport emissions of Thailand. The intensity of emissions from ADB's transport portfolio (loans or grants approved during 2000–2009) can be estimated using various indicators applied over project lifetimes. This analysis assumed the project lifetime of 20 years in line with general economic analysis of ADB's transport projects and calculated the CO_2 intensity indicators given below using both construction and operations emissions. The key findings are:

(i) **Output indicator – CO_2 intensity per km of transport infrastructure improved or constructed** was estimated to be 10,000 tons per km for ADB's transport portfolio. The output indicator for new expressways is higher at 88,000 tons per km constructed using ADB funding.

(ii) **Mobility indicator – CO_2 intensity per unit of passenger-km and freight-km by project type** was estimated for ADB transport projects. Expressways were much more efficient for passenger mobility than rural roads at 47 grams (g) vs. 74 g per passenger-km traveled. These two road types were equally CO_2 intense for freight at 61 g per ton-km. Railways were more efficient than roads by these criteria, at 20 g per passenger-km traveled and 23 g per ton-km traveled. An aggregate measure across all ADB projects for CO_2 intensity per unit of passenger and freight mobility will require additional data, which is currently not available.

(iii) **Investment indicator – CO_2 intensity per dollar of investment** provides values for each transport mode that are consistent with the other indicators. Across the portfolio, the aggregate CO_2 intensity per dollar of investment was found to be 31,035 tons per $1 million invested over the current projects' lifetime. However, within a specific context, this indicator should not be used on a stand alone basis but needs to be used in conjunction with the output and mobility indicators to ensure consistency.

Local pollution reduction and CO_2 reduction are correlated. Most transportation investments and strategies that reduce CO_2 pollution also reduce local pollution. The converse is also true. For example, expanded road capacity usually leads to long-term increases in CO_2 emissions as well as local air pollution because it increases the amount of traffic. Investments in railways and public transport may produce a reduction in emissions of both CO_2 and air pollution over the long term since such investments result in a reduction in the use of more polluting trucks, cars, and small vehicles in the same corridor. Investments in walking, cycling, bus rapid transit, and integrated traffic management are likely to reduce both CO_2 and local pollution. Road maintenance and traffic operations improvements similarly help curb both forms of pollution. Specific correlations between these vary widely by context and type of intervention as well as by pollutant.

Opportunities exist to support low carbon initiatives. Integrated urban transport initiatives offer major opportunities for low-cost CO_2 reduction that support efficient mobility and economic development. Improved traffic operations, intermodal freight initiatives to improve supply chain efficiencies and logistics, and road maintenance all cut CO_2 emissions. For example, if 20% of ADB's 2000–2009 expressway spending had instead been used to rehabilitate 2,515 km of railways, this alternative project mix would have resulted in reduced gross CO_2 emissions of 747 million tons, i.e., 5.7% lower than the estimated 792 million tons for the transport portfolio.

Construction emissions are usually small but can be significant in some cases. For most transport projects, construction emissions are small in proportion to operations emissions, which are typically measured over a period of 20 years or more. However, this is not true with respect to projects that involve extensive tunneling or elevated structures, as both require a lot more concrete and structural steel, which are carbon-intensive. CO_2 emissions associated with construction of metro rail transit (MRT) projects with underground tracks and stations can be equivalent to those associated with several years of operations of these projects. The latter are likely to be offset by long-term CO_2 reductions caused by the modal shift from high-carbon modes and the CO_2 benefits of transit-oriented development.

Emissions from expressways and trucks are higher than emissions from railways. A major share of ADB's activity has been in expressways and railways for long-distance travel. Expressways account for two-thirds of ADB's carbon footprint in transportation. Railways and highways each have a vital role to play and tend to serve different but partly overlapping market segments. Sustaining or growing the freight rail mode share for long-distance goods transport is an important part of a low carbon transport strategy. Boosting the efficiency of freight logistics and supply chains, reducing empty backhauls, and expanding the market for intermodal freight that enables a portion of shipments to be transported on lower carbon modes, such as railways or waterways, are also important to reducing CO_2.

Induced travel impacts both environmental and economic viability. Current ADB project appraisals do not properly account for induced travel and land use impacts that result from interventions, which significantly increase transportation capacity or cut transportation costs. These have profound effect on the amount and character of traffic and related CO_2 and local pollution emissions, typically increasing CO_2 by 17%–58% in several non-urban national highway cases examined for this study. The monetary value of CO_2 impacts, together with the higher vehicle operating costs, related to induced demand can affect the economic viability of projects, especially if they have marginal economic internal rates of return.

Integrated transport investment strategies allow more options for CO_2 reduction. A major area of opportunity for ADB to cut CO_2 emissions in the transport sector is through integrated transport initiatives that link transportation, regional and urban development, transport pricing and system management, and improvement of low carbon freight and public transport modes, walking, and cycling. Multiple examples from various countries show that a mix of investments in improved traffic operations, supply chain and logistics management, and intermodal connections and services for passengers and freight can improve mobility and system efficiency while reducing traffic growth, congestion, and pollution. Such a mix of demand- and supply-side strategies is typically much more cost-effective in producing desired economic and environmental outcomes than a supply-side strategy that focuses on merely creating new transport system capacity.

Traffic management and speed optimization can cut CO_2 emissions. Reductions in CO_2 of about 20% can be obtained by techniques to mitigate congestion, manage excess speeds, and smooth traffic flow for both urban and non-urban highways.

Mode shift to public transport, walking, and cycling can yield cost-effective CO_2 emission reduction. The most cost-effective urban mobility improvements are typically improvements in bus operations, replacing inefficiently run small buses in mixed traffic with high capacity buses operated on rights-of-way that give priority to these vehicles, bus stations, and improving conditions for walking and cycling in public transport corridors. These lead to more efficient utilization of scarce street space in terms of person-movements per meter of roadway. Such approaches especially benefit low and moderate income households and reduce CO_2, while delivering more person-movement capacity for a given amount of investment capital when compared with higher carbon transport investments.

Implications for ADB

In view of these findings, ADB could consider raising awareness of carbon emissions in project design, appraisal, and review. This could entail establishing baselines and forecasts against which to measure progress in reducing the intensity of future CO_2 emissions, recognizing the rapid growth in motorization and the trend in many DMCs toward a declining share travel by nonmotorized transport, public transport, and railway.

The carbon footprint tools developed and applied in this study can be further enhanced and applied to future ADB transport projects. This could support periodic evaluation of progress in reducing CO_2 impacts and local pollution from transportation across ADB's transport portfolio. Also, the tools in this EKB could help in better monitoring of the CO_2 and air quality impacts of ADB-funded transport projects, collecting critical data to support better GHG estimation and evaluation of other closely associated impacts, such as black carbon emissions from fossil or biofuels, which are potent contributors to climate change and cause serious harm to public health.

Further work is suggested to modify project economic analysis methods to better account for both induced travel, which affects cumulative vehicle operating cost expenditures, and the economic value of CO_2 and air pollutants affecting public health. Further development and application of the transport emissions evaluation model for projects appraisal tools to future ADB transport projects will help support these initiatives.

Estimation and monitoring of carbon emissions will have resource implications. Resource implications for the DMCs may need to be discussed with the borrower/client during country programming. The level of adoption of the new methodologies will depend on the DMCs' capacity.

Given below are recommendations for ADB Management's consideration and pilot testing over the next 2 years:

1. Adopt carbon emissions as a consideration for project design, review, and appraisal (paras. 123–129).

(i) In coordination with other multilateral and bilateral development agencies, ADB may consider developing the tools for estimation of carbon emissions of transport projects and applying them to selected projects on a pilot basis. This exercise will need to take into account developing member country capacities, e.g., Pacific island countries will have relatively low capacities.

(ii) In all countries, carbon emissions' friendly physical designs could be explored where found to be cost-effective and appropriate.

(iii) ADB may consider incorporating carbon emissions into the economic analysis and environmental assessments and including an alternative analysis in its project proposals to explore carbon emissions as a consideration in project selection.

2. Encourage modal shift in ADB investments (paras. 130–133).

(i) Currently, the prime factors for prioritizing and designing transport projects are provision of access and mobility. In line with its Sustainable Transport Initiative Operational Plan, ADB may additionally consider lowering the intensity of its carbon footprint by expanding its investments to cover new modes such as nonmotorized transport, bus rapid transit systems, and other such public transport systems.

(ii) ADB could strengthen its policy dialogue with developing member country governments to encourage low carbon projects.

3. Consider systematic indicators to monitor the intensity of carbon emissions from transport investments in alignment with the emphasis given in Strategy 2020 to climate change issues (paras. 134–136).

Intensity indicators for outputs, mobility, and investment have been introduced in this EKB for further consideration.

4. In partnership with DMC governments, align ADB's sustainable transport initiatives with nationally appropriate mitigation actions (para. 137).

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I. INTRODUCTION

A. Objective

1. The Asian Development Bank (ADB) has signaled a change in its transport investments to shift to low carbon growth across Asia and the Pacific.[1] The aim of this evaluation knowledge brief (EKB) is to contribute to this change—aimed at making ADB's transport sector assistance more protective of the environment. It is acknowledged that greenhouse gas (GHG) emission reduction is a global issue but the cost of emission reduction has to be borne locally, with support from various global incentive mechanisms. ADB is in a position to affect this change by providing options and related cost-benefit analysis at project conceptualization and appraisal, as well as to assist in attracting funding mechanisms geared for low carbon initiatives. This EKB provides a retrospective analysis of land transport projects approved by ADB in the last decade. It aims to inform future decision making through the emerging analytical tools and recommendations.

2. In addition to operations evaluation, the Independent Evaluation Department (IED) contributes to knowledge solutions through EKBs. The first EKB in 2009 addressed improving GHG efficiency of ADB's energy assistance. This EKB combines an evaluation of the indicative carbon footprint of ADB's land transport sector assistance with an identification of global good practices in reducing carbon emissions from transport projects. The latter is intended to contribute to a change in ADB's quality-at-entry as well as to the setting up of an emissions monitoring mechanism, which will lead to a lower carbon footprint in the long run. Since land transport comprising roads and railways forms 96.5% of ADB's overall transport portfolio, this EKB focuses on these subsectors with variations such as urban transit systems.

3. At the project level, the outputs of this EKB are (i) new analytical tools for carbon emissions intensity measurement, which feed into the Sustainable Transport Initiative Operational Plan;[2] and (ii) suggestions for improving the quality-at-entry, which feed into future project designs. At the portfolio level, this EKB provides an indicative carbon footprint of recently completed and ongoing ADB transport projects as well as intermodal comparisons. At a strategic level, this EKB provides suggestions for aligning study findings with Strategy 2020[3] and for inclusion of carbon emissions monitoring into the standard reporting process by ADB Management.

4. Although this EKB aims to reduce transport-related carbon emissions, enhancing mobility and affordable access will remain key drivers for support by ADB. The inclusion of carbon emissions monitoring and mitigation measures is envisaged to make transport more environmentally sustainable. This EKB does not cover climate change adaptation techniques.

B. Context

5. As Mahatma Gandhi said, "Be the change you want to see in the world." ADB has the potential to lead a change toward low carbon operations. Such action is important because the transport sector now contributes 13% of global GHG and 23% of energy-related carbon dioxide (CO_2) emissions.[4] Three-fourths of transportation-related emissions are from road traffic. Emissions from transportation are rising faster than from other energy-using sectors and are

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[1] Opening Remarks of ADB President H. Kuroda at the Transport and Climate Change Seminar, Copenhagen, on 13 December 2009.
[2] ADB. 2010. *Sustainable Transport Initiative – Operational Plan*. Manila.
[3] ADB. 2008. *Strategy 2020: The Long-Term Strategic Framework of the Asian Development Bank*, *2008–2020*. Manila.
[4] International Energy Agency (IEA). 2007. *World Energy Outlook 2007*. Paris.

predicted to grow globally by 80% from 2007 and 2030.[5] While scientific consensus exists about the need to sharply reduce GHG emissions to avoid catastrophic climate change in the coming decades,[6] many experts foresee a three- to five-fold increase in CO_2 emissions from transportation in Asian countries by 2030 compared with emissions in 2000, if no changes are made to investment strategies and policies.[7] This is driven by the anticipated six- to eight-fold increase in the number of light-duty vehicles and a large increase in the number of trucks, which could overwhelm even the most optimistic forecasts of improvements in vehicle fuel efficiency.

6. The correlation between GHG emissions and public health has been well documented with an almost unanimous scientific consensus on the links.[8] CO_2 forms the bulk of the GHGs and has the maximum contribution to the growth in global GHG emissions.[9] Other GHGs are methane, nitrogen oxide (NO_x), sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons. This report focuses on CO_2 or carbon emissions. Both the terms CO_2 emissions and carbon emissions are intended to mean the same thing, i.e., carbon dioxide emissions, in this EKB.

7. ADB plays an important role in shaping transport sector investment in Asia, not so much by the share of finance it provides but more in terms of related policy, regulatory, and technological considerations. Thus, it is vital that ADB plan, measure, monitor, and manage the CO_2 impacts of its sizeable transport project portfolio. ADB's transport sector lending grew from 16% of total ADB assistance in the 1970s to 33% in 2000–2005.[10]

8. Figure 1 shows that more than three-quarters of ADB's land transport assistance from 2000 to 2009 has been in road construction and improvement, with about 150 approved road projects. ADB's portfolio included construction or improvement of nearly 5,500 kilometers (km) of expressways and controlled access highways. Small-scale rural roads and road rehabilitation projects made up a much larger share of the length of roads improved through ADB lending, but represented a small share of the value of loans because of their much lower cost per km of improvement. ADB also invested in projects that produced nearly 6,000 km of railways from 2000 to 2009. Only 1.5% of ADB's transport loans during this period went into urban transport, but this is an area where ADB is likely to dedicate increasing resources in the future. Moreover, urban transport forms a major part of global carbon emissions; therein lie several solutions for mitigating the global impact of transport-related GHG emissions.[11]

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5 R. Kahn et al. 2007. *Transport and its infrastructure*. In B. Metz, O.R. Davidson, P.R. Bosch, R. Dave , L.A. Meyer, eds. *Climate Change 2007: Mitigation Contribution of Working Group III to the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge and New York: Cambridge University Press.

6 IPCC. 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the IPCC* (Core Writing Team, R.K. Pachauri and A. Reisinger [eds.]). Geneva.

7 World Business Council for Sustainable Development. 2004. *The Sustainable Mobility Project*. Geneva.

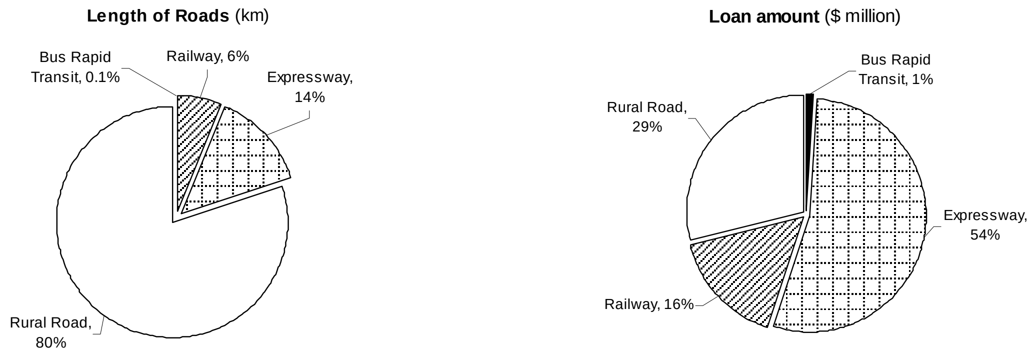
8 A. Haines et al. 2006. *Climate change and human health: impacts, vulnerability, and mitigation*. The Lancet. 367: 2101–2109; A. McMichael, R. Woodruff, and S. Hales. *Climate change and human health: present and future risks*. The Lancet. 367: 859–869.

9 The Kyoto Protocol covered six GHGs—CO_2, methane, nitrogen oxide, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons. IPCC has indicated that CO_2 is the most common GHG produced by anthropogenic activities, accounting for about 60% of the increase in radiative forcing. It suggests that gases like methane and nitrogen oxide, which are more potent than CO_2, have relatively minor contributions. Considering these factors and noting the intensity of growth of CO_2, and with fossil fuel being the primary driver of transport modes, the EKB focuses on CO_2 emissions only.

10 ADB. 2009. *ADB Infocus - Sustainable Transport*. Manila. http://www.adb.org/Media/InFocus/2009/sustainable-transport.asp (accessed 27 May 2010).

11 This is based on the argument that by 2050, more than 70% of the global population will be residing in cities. Cities will not only become bigger but would also multiply. In 1975, the number of cities in Asia having a population greater than 1 million was 80. By 2025, it is estimated that this number will rise to 332 cities (Population Division of the Department of Economic and Social Affairs. 2008. *World Urbanization Prospects*. United Nations. http://esa.un.org/unpd/wup/index.htm). With the increase in urbanization, the low carbon solutions for urban transport will enable a higher effectiveness in terms of reducing global GHG emissions.

Figure 1: Transport Projects approved by ADB During 2000–2009



ADB = Asian Development Bank, km = kilometer.
Source: Asian Development Bank database.

9. Within the 2010–2012 lending pipeline, projected transport lending is $3.4 billion per year.[12] It is valuable to understand the implications of past investments in this sector on CO_2 emissions. ADB's existing project appraisal and evaluation approaches follow the "business-as-usual" philosophy and do not consider carbon emissions at any stage.[13] However, as GHG mitigation becomes more widely and highly valued as a goal for investment and development, it becomes more important to assess how different activities, designs, and strategies might affect the GHG performance of projects and overall loan portfolios. Considering the future implications on the environment and climate, the impact of past operations will provide lessons that could enable better project designs in the future.

C. Recent Related ADB Initiatives

10. ADB's Regional and Sustainable Development Department has been analyzing a multi-criteria approach[14] as part of ADB's sustainable transport initiative to introduce climate change parameters and other parameters (such as local pollution and accidents) into economic analyses at appraisal. In parallel, ADB's regional departments such as the South Asia Department have been looking at climate proofing of projects by quantifying their impacts, i.e., quantifying the contribution of construction, maintenance, and road use activities on GHG emissions. The draft South Asia Department carbon footprint model has not yet been released at the time of this writing, but preliminary values from it were used in checking the reasonableness of values used in this EKB analysis.

11. ADB's East Asia Department completed a study on Green Transport, Resource Optimization in the Road Sector in the People's Republic of China (PRC),[15] which provides guidelines for advanced analysis in road project feasibility study and environmental impact assessment for energy saving and CO_2 reduction. These Green Transport guidelines provide operational guidance for road projects decision making by suggesting a theoretical and analytical approach to estimate and forecast energy consumption and CO_2 emissions from road traffic. These guidelines are applicable for the PRC and will need to be modified before applying to other

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[12] ADB. 2010. Sustainable Transport Initiative. Operational Plan. *Staff Working Paper*. Manila (May).
[13] Business-as-usual scenario refers to scenarios that encompass without project, no improvement, and no build situations. See para. 35 for the rationale of the business-as-usual scenario.
[14] This usually involves a combination of cost-benefit analysis, cost-effectiveness analysis, and qualitative analysis. The projects are assessed based on a set of criteria that includes various benefits and externalities.
[15] ADB. 2009. *Green Transport: Resource Optimization in the Road Sector in the People's Republic of China*. Manila.

Asian countries. The Green Transport study captures the network impact, so it has a different outlook from the EKB, which focuses on distinct transport corridors.[16]

12. In October 2009, ADB also published a report highlighting the relevance of assessing GHG emissions and air pollutants from the transport sector, proposing a methodology to be adopted that would support the development of sustainable low carbon transport systems in developing countries.[17]

13. This EKB has considered the outputs of these studies to the degree that they have been available to inform the framework for assessing projects approved between 2000 and 2009. It has also taken on board the current discussion in global forums and drawn key technical and economic data for the project and portfolio analyses.

D. Why ADB Needs to Address Carbon Dioxide in Transportation

14. Climate change has emerged as an important threat to economic development, environment, and public health. As a key development partner in Asia, ADB needs to find ways to mitigate the impact of climate change especially that linked to GHG emissions. ADB's long-term strategic framework Strategy 2020 includes a plan for scaling up "support for environmentally sustainable development, including projects to reduce carbon dioxide emissions and to address climate change" (footnote 3). It emphasizes ADB's commitment to help developing member countries (DMCs) to move their economies onto low carbon growth paths by modernizing public transport systems. It also highlights ADB's intention to reduce carbon footprint of Asia's cities. ADB's current safeguard policy statement requires active monitoring of GHG emissions. It states:

> The borrower/client will promote the reduction of project-related anthropogenic greenhouse gas emissions in a manner appropriate to the nature and scale of project operations and impacts. During the development or operation of projects that are expected to or currently produce significant quantities of greenhouse gases,[18] the borrower/client will quantify direct emissions from the facilities within the physical project boundary and indirect emissions associated with the off-site production of power used by the project. The borrower/client will conduct quantification and monitoring of greenhouse gas emissions annually in accordance with internationally recognized methodologies.[19] In addition, the borrower/client will evaluate technically and financially feasible and cost-effective options to reduce or offset project-related greenhouse gas emissions during project design and operation, and pursue appropriate options.[20]

15. This indicates the need for all highway and expressway projects to quantify GHG emissions since most of these will have annual emissions exceeding 100,000 tons. Apart from ADB's Safeguards Policy Statement, there are several other reasons that would spur ADB to address CO_2

[16] The Green Transport study enables measurement of operations emissions only, whereas the assessment models developed as part of this EKB enable measurement of both construction and operations emissions. Secondly, the Green Transport study requires a forecast of future vehicle speeds, whereas the EKB calculates using speed-flow equations and volume capacity ratios. Finally, the EKB facilitates the capping of future traffic growths.

[17] L. Schipper, H. Fabian, and J. Leather. 2009. Transport and Carbon Dioxide Emissions: Forecasts, Options Analysis, and Evaluation. *ADB Sustainable Development Working Paper Series*. No. 9. Manila: ADB.

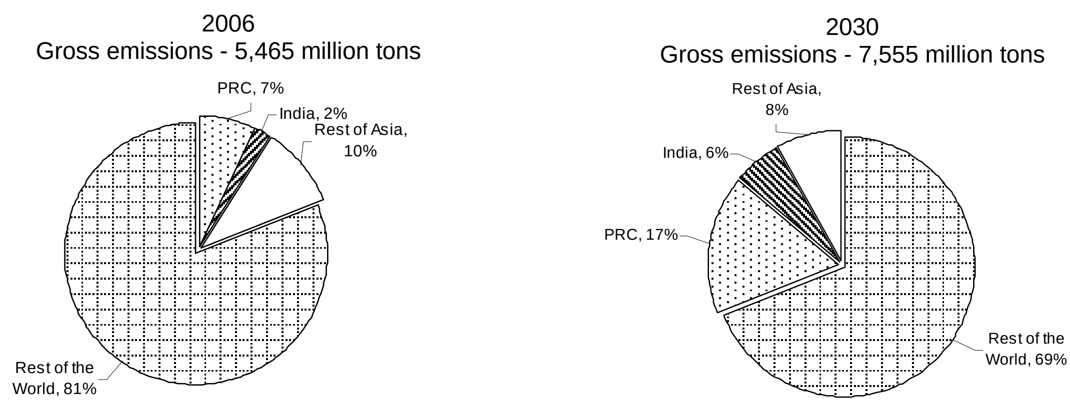
[18] The Safeguards Policy Statement cited that even though the significance of a project's contribution to GHG emissions varies between industry sectors, the significance threshold to be considered for these requirements is generally 100,000 tons of CO_2 equivalent per year for the aggregate emissions of direct sources and indirect sources associated with electricity purchased for own consumption.

[19] The Safeguards Policy Statement cited that estimation methodologies are provided by the IPCC, various international organizations, and relevant host country agencies.

[20] ADB. 2009. *Safeguard Policy Statement*. Manila.

emissions in its transport infrastructure portfolio. In terms of carbon emissions growth, transport-related emissions appear to be among the largest. Global transport sector CO_2 emissions in 2006 were 5,465 million tons and the International Energy Agency (IEA) forecasts that these will grow to 7,555 million tons by 2030 (Figure 2). Transport sector CO_2 emissions are forecast by the IEA to grow by 54% in Asia between 2006 and 2030, compared with 38% growth in the rest of the world.[21] The anticipated growth in motorization across Asia implies a huge rise in CO_2 emissions unless there are changes in not only transport and energy technology, but also in transport policies and management strategies to manage this growth.

Figure 2: Transport Sector Carbon Dioxide Emissions—Forecast Growth



PRC = People's Republic of China.
Source: International Energy Agency. 2008. *World Energy Outlook 2008*. Paris.

16. At a city level, even larger increases in CO_2 emissions are forecasted. A business-as-usual forecast of CO_2 emissions growth in Delhi, India would bring an increase in CO_2 emissions from 6.1 million tons in 2004 to 19.6 million tons in 2030, a 526% increase from 1990 levels. With wide adoption of much cleaner and more efficient motor vehicles, this might be limited to a 447% rise from 1990 levels. With substantial improvement of public transport, walking, and cycling, and such policies as road user charging to manage traffic, the rise in CO_2 emissions by 2030 might be held to a 235% rise above 1990 levels, or if combined with wide use of cleaner and more efficient motor vehicles to a 199% increase from 1990 levels.[22]

17. A 2009 ADB study found that Southeast Asia is one of the most vulnerable regions in the world to climate change unless steps for mitigation measures are adopted.[23] It also established that countries like Indonesia, the Philippines, Thailand, and Viet Nam could experience combined damages equivalent to more than 6% of their gross domestic product every year by the end of this century as a result of climate change. This impact on gross domestic product is expected to increase unless drastic CO_2 emission cuts are met and future emissions from developing countries are reduced. The transport share in the GHG emissions of developing countries is already significant and would continue to grow under the business-as-usual scenario.

18. There is a growing consensus among transportation, environmental, and development experts and stakeholders that actions must be taken on all possible fronts to move toward

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[21] IEA. 2008. *World Energy Outlook 2008*. Paris. Total emissions exclude international marine bunkers and international aviation.
[22] J. Woodcock et al. 2009. Public Health Benefits of Strategies to Reduce Greenhouse Gas Emissions: Urban Land Transport. *The Lancet*. 374: 1930–43.
[23] ADB. 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review*. Manila.

sustainable low carbon transportation, pursuing an “avoid-shift-improve” strategy.[24] This approach seeks to avoid unnecessary transport demand through smarter spatial planning, development of efficient logistic systems, and improved communications technology; to shift transport to lower carbon modes such as cycling, walking, and public transport; and to improve the GHG efficiency of the remaining transport systems, networks, vehicles, and fuels (footnote 17).

19. Strategies that reduce transportation sector CO_2 will also produce large public health benefits by cutting air pollution, which is of great importance to local stakeholders and developing countries. A 2009 study in the British medical journal, *The Lancet,* found that

> Although uncertainties remain, climate change mitigation in transport should benefit public health substantially. Policies to increase the acceptability, appeal, and safety of active urban travel, and discourage travel in private motor vehicles would provide larger health benefits than would policies that focus solely on lower-emission motor vehicles (footnote 22).

20. Strategies that reduce transportation sector CO_2 will curb black carbon soot pollution from transport, not only cutting health costs, but also yielding early reduction in high-potency climate change emissions. Black carbon is another potent climate forcing agent, considered to have global warming effects second only to CO_2; it is emitted in the transport sector from the burning of fossil and biofuels. Globally, fossil fuels including diesel are estimated to produce 40% of the world's black carbon.[25] Mitigating black carbon may be one of the most effective means of controlling climate change. Its combined climate forcing is 1.0–1.2 watt per square meter, which is as much as 55% of total CO_2 forcing—larger than the forcing caused by the other GHGs such as methane, chlorofluorocarbons, NO_x, or tropospheric ozone (footnote 25). Shifting fuel sources from fossil fuels to other sources such as liquefied petroleum gas, compressed natural gas, or plug-in electric hybrids can all reduce black carbon. Diesel oxidation catalysts for diesel vehicles, which have been in use for over 30 years, can be used on almost any diesel vehicle and can eliminate 25%–50% of black carbon emissions.[26] This study does not analyze black carbon pollution but focuses mainly on CO_2 emissions.

21. There is an opportunity for ADB to profile itself as a sustainable development bank and position itself for competitive advantage. ADB will continue to support transport projects, which are crucial for economic development in Asia. Where possible, ADB needs to consider alternatives that are cost-effective and also reduce GHGs. This EKB provides the tools for monitoring carbon emissions from transport projects and identifies options for reducing future emissions. It is intended to be a combination of evaluation and identification of good practices to raise awareness on how to analyze the intensity of carbon emissions during project appraisal.

II. EVALUATION METHODOLOGY

A. Scope of the Study

22. To gain a general idea of the portfolio impact, this EKB analysis has been conducted to establish placeholder values for future deliberations, i.e., figures for carbon emissions intensities that have been derived using first generation models. It is recommended that these values be

[24] ADB. 2009. *Promoting Sustainable, Low Carbon Transport in Asia*. Manila. http://www.adb.org/Documents/Brochures/Low-Carbon-Transport/Low-Carbon-Transport.pdf

[25] V. Ramanathan and G. Carmichael. 2008. *Global and Regional Climate Changes due to Black Carbon.* Nature Geoscience 1, no. 4: 221–227. http://www-ramanathan.ucsd.edu/publications/Ram_Carmichael-NatGeo1-221.pdf (accessed 27 May 2010).

[26] Manufacturers of Emission Controls Association. 2007. *Emission Control Technologies for Diesel-Powered Vehicles*. Washington, DC.

considered preliminary and be refined[27] further with more project applications and incremental improvements to the analysis tools. Currently, the absence of robust data limits the development of analytical tools.

23. Examining ADB's transport operations in isolation is difficult, considering that ADB's assistance is accompanied by investments of other development partners and government sources. In addition, considering the difficulty of estimating the total footprint of projects that have large components of funds allotted for capacity building, road safety, institutional development, and other activities, the EKB considers life cycle costs of only the civil works component of the projects, i.e., the sources of emissions linked to construction activity, as well as operations.

24. This EKB developed indicators from a representative sample of ADB and non-ADB projects to determine the carbon footprint of ADB transport projects approved between 1 January 2000 and 31 December 2009. The current list of projects includes non-ADB funded transport projects in Asia, e.g., Manila, Philippines and Bangalore, India. Several ADB-funded projects do not have sufficiently documented information, which restricts the analysis with reasonable accuracy. The non-ADB funded projects included in the EKB analysis are similar in nature to those funded by ADB in the past and to those that might be funded by ADB in the future, e.g., nonmotorized transport (NMT). Appendix 1 contains the list of projects evaluated in depth. The transport sector assistance during this period was fairly uniform, i.e., projects funded by ADB involved road improvements or construction of railways. Unlike the energy sector, there were no concerted efforts at introducing GHG emission reductions until recently.

B. Methodology

25. The EKB has adopted a case study method to develop carbon intensity indicators, based on a review of existing methods and knowledge, and then extrapolated results across ADB's transport sector portfolio. The portfolio analysis, including the carbon footprint measurement, is based on the development of coefficients using a sample of projects (Appendix 1). It confirms knowledge about many common aspects of issues in the transport sector and provides support for new information and recommendations. Appendix 2 shows the various stages of the activities leading up to preparation of the EKB.

26. Based on the study methodology outlined in the approach paper approved on 14 August 2009,[28] a model was developed for assessing and analyzing carbon emissions and air pollutant emissions of transport projects funded by ADB. The model has been developed in conjunction with a parallel initiative for developing standardized evaluation tools for GHG analysis for the Global Environmental Facility (GEF) program. Consultations and presentations have been made to ADB's transport and environment communities of practice during the course of this study. The tools used for this EKB have undergone a peer review by internal and external audiences. These tools are in the process of being adapted by GEF for their project analysis, and are being further peer-reviewed by members of the GEF Scientific and Technical Advisory Panel and other global experts. It is anticipated that these tools will continue to be refined through an open, peer-reviewed empirical process grounded in a growing body of data from worldwide project and program analyses, in cooperation with GEF and its stakeholders, including ADB.

[27] It is recommended that more refinements are carried out by applying these models on other projects not covered by this EKB.
[28] ADB. 2009. *Special Evaluation Study on Reducing Carbon Emissions from Transport Projects—Evaluation Approach Paper*. Manila.

27. The quantitative analysis has followed the general method of activity–structure–intensity–fuel (ASIF) models, which are the most common framework for transportation CO_2 analysis. Adapting from ADB's prior work on transport sector carbon footprint analysis (footnote 24), this EKB has developed a set of spreadsheet-based models to evaluate the CO_2 impacts of rural roads, urban roads, bikeway projects, expressways, light rail and metro rail transit (MRT) projects, bus rapid transit (BRT) projects, and railways. These transport emissions evaluation models for projects (TEEMPs) consider passenger and freight travel activity, the shares of trips by different modes and vehicle types (structure), fuel CO_2 efficiency (intensity), and fuel type, validated by more detailed emission factor models. The models directly estimate CO_2 emissions for a business-as-usual case (a no-action alternative) vs. one or more alternative modal investment interventions and calculate scenario differences. The models consider induced traffic demand generated by changes in the generalized time and money cost of travel by different modes, building on best practice analysis techniques. Some TEEMPs, such as that for BRT, are more thoroughly developed than others to take into account the impact of best design and operational practices on travel demand, system performance, and emissions. Appendix 3 provides a more thorough discussion of the models and provides a guidance for future users of these models.

28. These construction and operations CO_2 emission models were applied to a representative sample of ADB and non-ADB projects completed or approved over the past decade to estimate the typical quantity of CO_2 emissions associated with different project types. In each model, business as usual refers to no project or no modifications to the existing situation, and intervention refers to the project being implemented (such as a BRT system). This is in line with the current practice used in the economic analyses of transport projects. Emission savings were quantified under the assumption that no major improvement would have happened in the scenario without the project. This could be viewed as a limitation since in reality, there could be some intervention funded either by the public authorities or by another financier; and the intervention could vary substantially from case to case. However, this EKB relies on adapting the analytical approach agreed to by the United Nations Framework Convention on Climate Change to evaluate the GHG impacts of investments under the Clean Development Mechanism and other carbon finance frameworks, such as the GEF. The common feature of these is that emissions impacts are viewed by considering what would have happened without the project intervention, i.e., a scenario-based build vs. business-as-usual comparison.

29. A sensitivity analysis was carried out for various scenarios, e.g., what would have happened to emission levels if a road widening had led to lesser or greater induced traffic, or if a BRT system was poorly implemented as opposed to well implemented (para. 106).

30. A portfolio analysis was undertaken for ADB transport sector projects (both loans and technical assistance projects) approved between 2000 and 2009. The sample includes a combination of completed and ongoing projects. For urban transport, ADB's portfolio is currently growing and does not include any completed MRT project. In this case, the sample included ongoing projects. The emission factors by project type were multiplied by the unit of length or lane-km for the project type to forecast the approximate portfolio CO_2 emissions.

31. The resultant CO_2 portfolio level estimates should be considered preliminary and refined further with more project applications, incremental near-term improvements to the analysis tools, and additional project classification parameters. It would be useful in the near future to monitor the following coefficients that have been developed by this EKB: (i) output coefficient for tons of CO_2 per km of transport infrastructure constructed or planned, (ii) mobility coefficient for tons of CO_2 per vehicle km travel (traffic), and (iii) investment coefficient for tons of CO_2 per $ million investment (project cost).

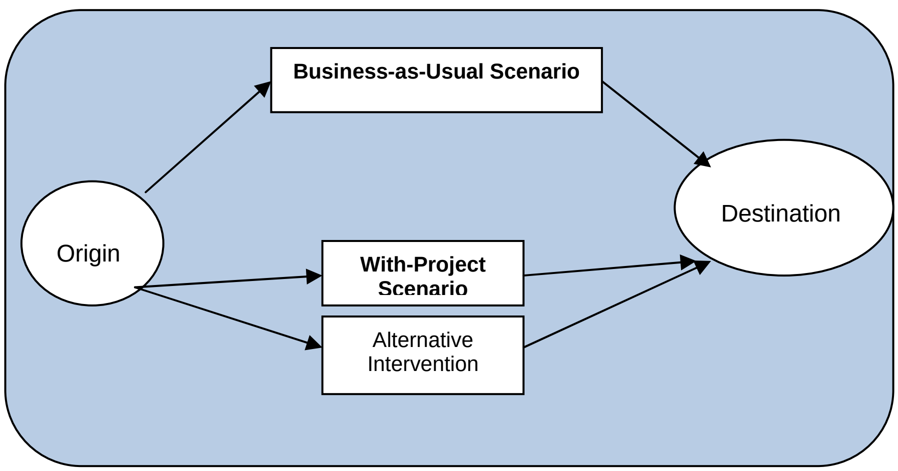
C. Framework for Assessing Carbon Emissions from Transport Projects

32. TEEMPs are Microsoft Excel-based models for the following land-based transport modes: (i) rural roads, (ii) urban roads, (iii) bikeway projects (NMT), (iv) rural expressways, (v) light rail transit (LRT)/MRT projects, (vi) BRT system projects, and (vii) railway projects.[29]

33. Appendix 3 provides a framework for using the TEEMPs. The TEEMPs measure the carbon emissions for both the project construction as well as operations, i.e., for the project life cycle. The construction emissions are estimated using the most appropriate empirical data available from ADB documents—appraisal reports, civil works contracts, and completion reports. These are a compilation of standard carbon intensity factors based on the embedded carbon energy in material inputs such as concrete, asphalt and steel, and the activities of construction. For road projects, the construction emissions are relatively lower than the operations emissions. In view of this, the EKB has focused more on options to mitigate the latter.

34. An impact assessment report was prepared by IED detailing the main findings of the TEEMPs. This report is provided in the supplementary appendix. It includes details on the evaluation methodology and technical and economic assumptions. Figure 3 shows the basic analytical framework behind the TEEMPs.

Figure 3: Basic Structure of Transport Emissions Evaluation Model for Projects



Source: Independent Evaluation Department.

35. In each TEEMP, the business-as-usual scenario refers to no project or no change to the existing situation; this is compared with the "with-project scenario." Emission savings are quantified under the assumption that no major improvement would have happened in the scenario without the project. Box 1 summarizes the dynamic baseline that has been used to describe the business-as-usual scenario. Impacts on travel-related emissions are first evaluated by looking at the travel characteristics and emissions for trips envisioned to make use of the proposed project in the with-project scenario. A proposed project is compared against one or more alternative scenarios. The model is used to look at the circumstances, modes, and characteristics of travel-related emissions in the project corridor in the absence of the proposed project under a business-as-usual scenario. In some cases, the TEEMP is used to evaluate what would be the characteristics of travel-related emissions in the corridor assuming an

[29] These models can be downloaded using the following link – http://www.adb.org/evaluation/reports/ekb-carbon-emissions-transport.asp.

alternative investment, or given different assumptions about the effectiveness of the proposed project in diverting trips from or to various modes, or affecting other aspects of travel demand and behavior, such as induced travel. In each case, the same set of origin–destination trip pairs is evaluated against the baseline and alternative circumstances or assumptions unique to the scenario. The traffic-related emissions characteristics provide a quantified estimate of the impact. By subtracting or dividing the differences in impact estimates between scenarios, the models calculate the net impacts in absolute or relative terms.

Box 1: Dynamic Baselines for Business-as-Usual Scenario

The TEEMPs developed as part of this EKB adopt a dynamic baseline that reflects changes in various macroeconomic factors and policies in the context of the project. Under the United Nations Framework Convention on Climate Change, it appears likely that dynamic baselines may be used to evaluate unilateral and supported nationally appropriate mitigation actions in the transport sector. Such baselines include trends in motor vehicle ownership and use, changes in public transport patterns, transport mode shares, composition of the motor vehicle fleet, and sometimes changes in the attributes of motor fuels. These changes are largely characterized by variations in traffic and vehicle speeds, which have been captured by the TEEMPs. In contrast, static baselines compare conditions at some fixed time either current or past, assuming constant parameters of traffic, vehicle speed, vehicle ownership levels, and transport and trip mode share. Appendix 3 provides further details of the dynamic baselines.

EKB = evaluation knowledge brief, TEEMP = transport emissions evaluation model for projects.
Source: Independent Evaluation Department.

36. The TEEMP framework and carbon footprint analysis were based on the following parameters:

(i) The models are based on the ASIF methodology, which connects activity (passenger and freight travel) with structure (shares by mode and vehicle type) with intensity (fuel efficiency) with fuel type.[30]
(ii) The models draw on detailed methodologies such as the Computer Programme to Calculate Emissions from Road Transport (COPERT)[31] and allow users to put in default emission factors to capture the impact of speed primarily.
(iii) The impact of age (age deterioration factors), grade, and temperature have not been considered in the TEEMP assumptions.
(iv) The TEEMPs have been designed for use at appraisal to compare project alternatives using data collected at the feasibility stage. The assessment includes data collated to capture fuel savings, which is a primary benefit and cost of the project, i.e., vehicle operating cost (VOC).
(v) The fuel split currently captures gasoline and diesel fuel only.
(vi) Detailed and consistent data was not available for several ADB-funded projects. In view of this, other non-ADB funded projects were included. Appendix 1 gives details of these projects.

37. Appendix 3 provides a detailed methodology report to support the use of the models and understand underlying assumptions. This is envisaged to serve as a tool for mainstreaming of the emissions intensity estimation and inclusion in the economic analysis model.

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[30] See L. Schipper, G. Celine Marie-Lilliu, and R. Gorham. 2000. *Flexing the Link between Transport and Greenhouse Gases: A Path for the World Bank*. IEA: Paris (June).

[31] COPERT is a Microsoft Windows software tool for the estimation of GHG emissions from road transport. The emissions cover the major pollutants viz. carbon monoxide, NO_x, particulate matter, and sulphur dioxide; as well as GHGs including CO_2. COPERT has been developed by the European Topic Centre on Air and Climate Change and is supported by the European Environment Agency. The COPERT 4 methodology has been included in a guidebook developed by the United Nations Economic Commission for Europe Task Force on Emissions Inventories and Projections.

D. Limitations of the Study

38. The key limitation of this EKB is that data available from recent ADB projects often does not include information needed to estimate CO_2 emissions with reliability. As a result, the EKB has supplemented this data with non-ADB project data to estimate a number of parameters. In some cases, significant simplifying assumptions have been made based on expert judgment to provide for internally consistent and complete analysis of CO_2 emissions. Appendix 4 provides details of the limited data available from ADB's project management system. Data availability has also constrained the number of projects that could be included in the detailed analysis of modal coefficients. As a result of the limited sample size, the initial estimate of the overall carbon intensity of ADB projects approved between 2000 and 2009 should be viewed as preliminary, with a potential margin of error. For example, the operations emissions have been analyzed over a period of 20 years whereas the typical life of a railway project could be twice as much. Data constraints tend to restrict further extrapolation. The EKB analysis has excluded CO_2 and energy use associated with vehicle manufacture, production, or demolition, which typically constitutes one-fourth to one-fifth of the life cycle CO_2 emissions of light-duty motor vehicles.[32] Finally, although the TEEMPs are designed to estimate particulate air pollution, this has not been incorporated into this study because of constraints on data, despite the importance of such pollution impacts on public health and related costs and benefits.

III. KEY FINDINGS OF THE CARBON FOOTPRINT ANALYSIS

39. The carbon footprint analysis for this study and a review of recent related global literature support a number of findings that are relevant to future ADB transport project analysis, design, and lending. These are discussed below. More detailed supporting analysis can be found in Appendix 5. This section has segregated the findings under the following headings:

(i) Indicative carbon footprint and savings achieved by transport sector assistance,
(ii) Local pollution reduction and CO_2 reduction are correlated,
(iii) Construction period emissions, and
(iv) Operations period emissions for non-urban and urban transport subsectors.

40. These findings are based on a combination of data analysis of ADB and non-ADB funded projects, and literature review. In most cases, the findings of the data analysis have confirmed the prevailing view as evidenced in the various reports published by international agencies.

A. Indicative Carbon Footprint and Savings Achieved by Transport Sector Assistance

41. This section analyzes the carbon footprint of ADB's transport sector assistance approved between 2000 and 2009. Subsequently, it identifies intensity indicators for outputs, mobility, and investment, which could be benchmarked in the future. It gives the baseline figures for these coefficients. Finally, it provides a sensitivity analysis to assess the potential impact of changes in the modal mix of ADB's investments.

1. Transport Sector Carbon Footprint

42. Table 1 shows the carbon emissions contributions by each transport mode. The initial estimate of the overall carbon footprint of ADB's transport sector assistance approved between 2000 and 2009 is 792 million tons, covering both construction and operations emissions. This is

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[32] H. Kato. 2010. *Lifecycle Impact Assessment Method Based on End-Point Modeling. Address to Symposium on United States–Japan Cooperation on Integrated Approach to Transportation: Improving Efficiency and Reducing Emissions from Passenger Vehicles.* Washington, DC (27 April).

the aggregate carbon footprint of 78,983 km of infrastructure development using ADB's assistance. To put this cumulative total of emissions into perspective, the set of ADB transport projects approved between 2000 and 2009 is estimated to account for 39.6 million tons of CO_2 per year, which could be comparable to the annual land transport emissions of Thailand (44 million tons CO_2 in 2005) (footnote 17). The quantum of emissions from ADB's transport projects is about 2% of the United States of America's (USA's) annual transport emissions for 2008.[33]

Table 1: Estimated Carbon Footprint (Construction + Operations Emissions) of ADB's Road Transport Projects Approved During 2000–2009

Transport Mode[a]	**Total Kilometers Constructed/ Improved**	**Number of Lanes**	**TEEMP Footprint Indicator** (CO_2 tons/km/lane/year)	**Cumulative CO_2 Emissions for 20 Years** (million ton)
(1)	**(2)**	**(3)**	**(4)**	**(5)**
Expressways	5,490	4	1,100	483
Rural Roads	2,893	2	250	29
Rehabilitated Roads	64,621	1–2	15	29
Bus Rapid Transit	13	2	1,100	1
Railways	5,966	1	2,100	251
Metro Rail Transit[b]	0	2	1,200	0
Bikeways[b]	0	1	1.2	0
Total	**78,983**			**792**

ADB = Asian Development Bank, CO_2 = carbon dioxide, km = kilometer, TEEMP = transport emissions evaluation model for projects.

[a] The modes of transport are categorized as follows: (i) expressways are four-lane intercity dual carriageways costing more than $1 million per km; (ii) rural roads are two-lane single carriageways to expand existing capacity in the non-urban context, costing $0.5 million–$1 million per km; (iii) rehabilitated roads are either 1 lane or 2 lane (taken as an average of 1.5 lane) single carriageways to improve pavement surface, costing less than $0.5 million per km; (iv) bus rapid transit systems involve a combination of public transport system and traffic management; (v) railways are intercity freight and passenger transport systems; (vi) metro rail transit are urban rail-based systems with two tracks; and (vii) bikeways are urban nonmotorized transport systems that provide mobility through improved infrastructure.

[b] ADB has yet to approve any metro rail transit or bikeways project. Hence, the cumulative CO_2 emissions have not been estimated here.

Source: Independent Evaluation Department estimates.

43. Table 1 shows the relative intensity of the carbon footprint as well as the gross carbon emissions. Typically, ADB-funded projects tend to increase or rehabilitate the size of the transport infrastructure, e.g., an expressway project will increase the number of lanes of an existing two-lane highway to a four-lane expressway. The number of lanes has a significant impact on the total carbon footprint as it influences the demand, volume to capacity (V–C) ratios, speed, and construction emissions.

44. The size of the construction emissions varies between 1.2% and 24.0% of total (construction + operations) emissions. This estimate is based on the quantity of three key construction materials used—cement, steel, and bitumen. Although in absolute terms the construction emissions of ADB-funded rural roads are low, they form about 24% of total emissions in this category since the operations emissions are also low. Construction emissions of ADB-funded railway projects are about 2.4% of total emissions in this category.

45. Expressways account for over 60% of ADB's transportation project-related emissions, 483 million tons, as nearly 22,000 lane-km of expressways were financed by ADB during the period, and these facilities generally produce a high level of CO_2 per km. Railways account for most of the rest, about 32%, which is a function of the high tonnage of bulk and other freight

[33] United States Department of Energy. 2009. Emissions of Greenhouse Gases in the United States. Energy Information Administration. http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html (accessed 14 May 2010).

carried per track-km of rail—this adds up to considerable energy use even if railways are considerably more energy-efficient per ton-km than trucks for freight haulage. Road rehabilitation projects on average have a small carbon footprint since they do little to induce new traffic, and they improve vehicle operating efficiency. Although these road rehabilitation projects formed 82% of the total km of transport facilities financed for construction or reconstruction by ADB during the past 10 years, they contributed to 4% of the CO_2 footprint of ADB's transport portfolio. Rural road capacity expansion projects typically have only a modest carbon footprint, and these projects made up 4% of the km of transport facilities improved by ADB during the period, so overall emissions from these were also small. ADB had only marginal investments in other types of transport facilities—BRT, MRT, and nonmotorized facilities—during 2000–2009.

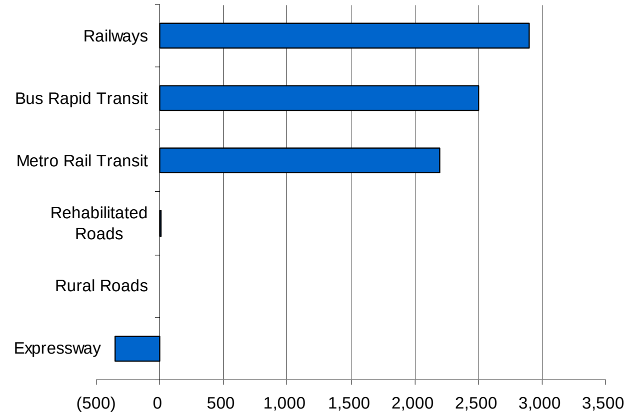
46. **Carbon footprint indicator.** The figures from the fourth column of Table 1 have been calculated using data available from ADB's project management system. The footprint indicator estimates the annualized CO_2 emissions from construction and operation per lane-km of capacity over 20 years. Table 1 (column 4) shows the CO_2 emissions (tons/km/lane/year) for railway projects appear higher than those for expressways since these have been estimated for each lane of the transport mode. An appropriate comparison between expressways and railways will require multiplying the number of lanes (column 3) with the TEEMP footprint indicator for each transport mode.

47. **Overall savings in the intensity of carbon emissions.** This EKB used the TEEMP to estimate for each project the likely effect on transport sector CO_2 emissions. This estimate is based on considering the relative change in CO_2 emissions, comparing the project scenario with a business-as-usual scenario. This analysis adapts the build versus no-build methodological framework commonly employed in economic and environmental appraisals, including climate finance.[34] The estimated savings in the intensity are demonstrated in Figure 4. The main findings are as follows:

(i) Expressway projects were found to increase CO_2 emissions over their 20-year lifetime compared with business as usual because of effects on induced travel that overwhelm the short-term benefits of curbing low-efficiency congested traffic.
(ii) Rural roads and road rehabilitation projects were found to have a neutral or slightly reduced effect on CO_2 emissions compared with business as usual. These improve the efficiency of traffic flow and reduce low-speed high carbon intensity travel. They enable moderate speed and lower carbon intensity travel, and are characterized by only a modest induced traffic impact. Moreover, where induced traffic is significant for rural roads in developing countries, often it is from a low initial traffic volume.
(iii) Bikeways were found to produce modest reductions in CO_2 emissions by diverting some trips from more carbon-intense modes.
(iv) Public transport investments and railway improvements, while generating new CO_2 of their own, more than offset those emissions when they divert passenger and freight movements from higher carbon modes and improve the efficiency of traffic flows.

[34] For example, the Kyoto Protocol, Article 12, para. 5 states that "Emission reductions resulting from each project activity shall be certified by operational entities … on the basis of: … (c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity."

Figure 4: Savings in the Intensity of Carbon Dioxide Emissions
(CO_2 tons saved per kilometer per lane per year)



CO_2 = carbon dioxide.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports.

2. Key Intensity Indicators of Carbon Emissions

48. This EKB developed three sets of carbon intensity indicators to assess the total of about 78,983 km of transport infrastructure assistance projects approved for finance by ADB between 2000 and 2009. Table 2 provides the comparison of CO_2 emissions intensity from both construction and operations emissions for outputs (per km of transportation infrastructure improved or constructed) and mobility (passenger-km and freight-km). Appendix 3 provides more details on this analysis. Depending on the data available and project priorities, these indicators will need to be given appropriate weights. In other words, it is important to use them as a basket of indicators to ensure a comprehensive coverage of all aspects. These indicators provide the combined intensity of carbon emissions emanating from both construction and operations of transport projects, i.e., over the project life cycle.

Table 2: Carbon Dioxide Intensity per Unit of Output and Mobility of ADB's Transport Projects Approved During 2000–2009

	Business-as-Usual Scenario			With-Project Scenario		
	Output Indicator	Passenger Mobility CO_2 Intensity	Freight Mobility CO_2 Intensity	Output Indicator	Passenger Mobility CO_2 Intensity	Freight Mobility CO_2 Intensity
Project Type (1)	CO_2 tons/km Transport Infrastructure (2)	CO_2 grams per passenger-km (3)	CO_2 grams per ton-km (4)	CO_2 tons/km Transport Infrastructure Improved (5)	CO_2 grams per passenger-km (6)	CO_2 grams per ton-km (7)
Expressways	63,650	59	81	88,000	47	61
Rural Roads	10,000	84	73	10,000	74	61
Rehabilitated Roads	800	149	199	600	55	68
Bus Rapid Transit	134,000	137	NA	44,000	28	NA
Railways[a]	63,650	59	81	42,000	20	23
Metro Rail Transit	134,000	137	NA	48,000	38	NA
Bikeways[b]	NA	NA	NA	24	NA	NA

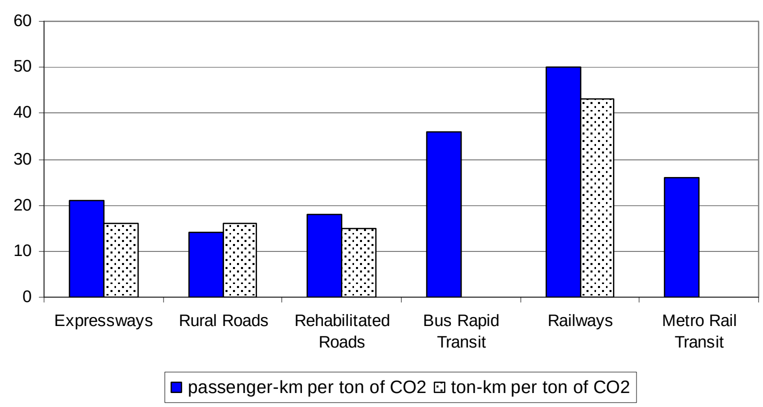
ADB = Asian Development Bank, BRT = bus rapid transit, CO_2 = carbon dioxide, km = kilometer.
[a] The business-as-usual scenario for railway is considered as an expressway.
[b] ADB has had limited involvement in bikeways subsector.
Source: Independent Evaluation Department estimates using the transport emissions evaluation model for ADB projects.

49. **Output indicator— CO_2 intensity per kilometer of transport infrastructure improved or constructed.** An output metric that can be readily applied to evaluate the carbon footprint of ADB transport projects approved between 2000 and 2009 is the CO_2 intensity per km of transport infrastructure constructed. The output indicator in Table 2 (columns 2 and 5) highlight the relative volumes of traffic and brings out the impact of expressways. It indicates that because rural road projects typically involve a low volume of traffic, they have correspondingly low emissions. Expressways show higher emissions in the project scenario owing to the induced traffic. On the other hand, the other modes—BRT, MRT, and railway investments—result in net savings in carbon emissions in the project scenario.

50. A major finding of this EKB is that expressways funded by ADB during this period are likely to boost CO_2 emissions over their 20-year project life cycle by 154 million tons compared with the business-as-usual case (Figure 4). Investments by ADB in railways, road rehabilitation, and BRT during the period, while generating CO_2 emissions of their own, more than offset these emissions. This is because ADB investments in the latter subsectors have reduced congestion. Table 2 shows the intensity of the impact of ADB projects during 2000–2009, which can be used as baseline for future comparison.

51. **Mobility indicators.** Those planning transportation systems often seek to maximize mobility or access provided in the interaction of transport and regional economic systems while minimizing cost or externalities. This EKB estimated ton-km and passenger-km per ton of CO_2 emitted for construction and operations over the lifetime of various ADB and non-ADB transport investments. Figure 5 shows the EKB's findings for how these vary by project type for passengers and freight. This indicator is the inverse of the carbon emissions per passenger-km and per ton-km, which indicate the carbon intensity per unit of mobility. It is a valuable metric for evaluating the effectiveness of transport investments considering both economic development and environmental objectives simultaneously. The implication of this mobility measure is that railways, MRT, and BRT are more efficient than highways in terms of providing mobility per ton of CO_2 emitted. Railways provide more freight mobility per ton of CO_2 emitted than roads.

Figure 5: Mobility per Ton of Carbon Dioxide for Passengers and Freight



CO_2 = carbon dioxide, km = kilometer.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports.

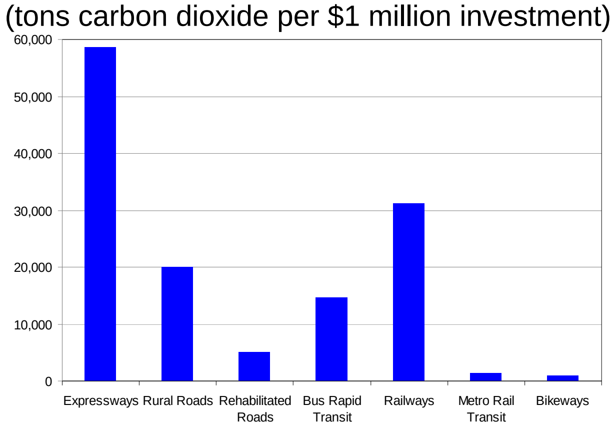
52. **Passenger mobility.** The carbon intensity per unit of passenger mobility is shown in columns 3 and 6 of Table 2. Rural road investments were found to reduce CO_2 emissions per passenger-km slightly from 84 grams (g) to 74 g, a 12% drop compared with a business-as-usual scenario. Expressway investment yields a slightly greater percentage reduction from 59 g per passenger-km to 47 g per passenger-km, a 20% drop. Investment in expressways induces

significantly greater traffic but it also increases the efficiency of individual travel, which results in lower CO_2 emissions per passenger-km. Road rehabilitation yields a much larger reduction, from 149 g per passenger-km to 55 g per passenger-km, a 63% drop. Railway investment causes CO_2 emissions to drop from 59 g per passenger-km to 20 g per passenger-km, a 66% drop, assuming passengers are diverted from expressways in the business-as-usual scenario. MRT investments cut emissions from 137 g per passenger-km in the business-as-usual case to 38 g per passenger-km in the project scenario, a 72% drop. BRT investments show the greatest efficiency, with emissions dropping from 137 g per passenger-km to 28 g per passenger-km, an 80% reduction.

53. **Freight mobility.** The figures in columns 4 and 7 of Table 2 bring out the differential carbon intensities for freight mobility among the various transport modes and enable portfolio wide comparison. Rural road investments reduce CO_2 emissions per ton-km slightly, from 73 g to 61 g, a 16% drop, when compared with a business-as-usual scenario. Expressway investment yields a slightly greater percentage reduction, from 81 g per ton-km to 61 g per ton-km, a 25% drop, compared with a business-as-usual scenario. Road rehabilitation yields a much larger reduction, from 199 g per ton-km to 68 g per ton-km, a 66% drop, compared with no rehabilitation. Railway investment causes CO_2 emissions to drop from 81 g per ton-km to 23 g per ton-km, a 72% drop, assuming freight is diverted from expressways in the business-as-usual scenario.

54. **Investment intensity.** The intensity of CO_2 emissions per unit of capital spending was also estimated by this EKB and is shown in Figure 6, but this needs to be used in conjunction with the other intensity coefficients, especially the output indicator. This indicator on its own does not bring out the underlying issue, i.e., it costs much more to build an MRT system than a BRT system to provide equivalent public transport capacity; and MRTs are less energy-intense during operations. A combination of this results in low CO_2 intensity per unit of spending for MRTs. However, this intermodal comparison needs to be done in conjunction with other coefficients (including output and demand) to obtain an overall picture. Figure 6 shows that expressways emit the most CO_2 per unit of spending and bikeways the least. Railways emit roughly half as much CO_2 emissions per unit of transport capital spending as expressways, as they are much more efficient at moving freight on a ton-km basis than roads.

Figure 6: Gross Carbon Dioxide Intensity per Unit of Capital Cost by Project Type
(tons carbon dioxide per $1 million investment)



Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports.

55. **Sensitivity analysis.** Given below are various scenarios of the likely impact if ADB had adopted alternative investment strategies in the past. Chapter IV of this EKB provides details on various strategies that ADB can adopt in the future. Expressways provide a major contribution to economic development by enabling trade and access to distant locations. On the other hand, a

cost associated with this development needs to be recognized. Table 3 provides a sensitivity analysis for various scenarios providing an indication of the likely impact of this cost. This analysis does not purport that expressway development should be stopped, but it signifies the relative intensity of carbon emissions—visible in both developed and developing countries.

Table 3: Sensitivity to Shifting Investments from Expressways to Alternative Modes

Percent Reduction in Expressway Investment	Alternative Mode of Investment	Change in ADB's Carbon Footprint
Base Case – 0% reduction		792 million tons
Alternative 1 – 10% reduction	32,942 km of bikeways	745 million tons (decrease of 6%)
Alternative 2 – 20% reduction	2,515 km of railways	747 million tons (decrease of 5.7%)
Alternative 3 – 30% reduction	823 km of bus rapid transit systems	684 million tons (decrease of 14%)
Alternative 4 – 50% reduction	6,863 km of roads rehabilitation, 824 km of bus rapid transit systems, and 32,942 km of bikeways	591 million tons (decrease of 25%)

ADB = Asian Development Bank.
Source: Independent Evaluation Department.

56. In other words, Table 3 shows that a cumulative redirection of half of ADB's expressway funding to low carbon transport projects would have cut the annual carbon CO_2 emissions from projects approved by ADB between 2000 and 2009 to 16 million tons, which is about equal to the magnitude of the annual Metro Manila passenger transport emissions in 2015.[35]

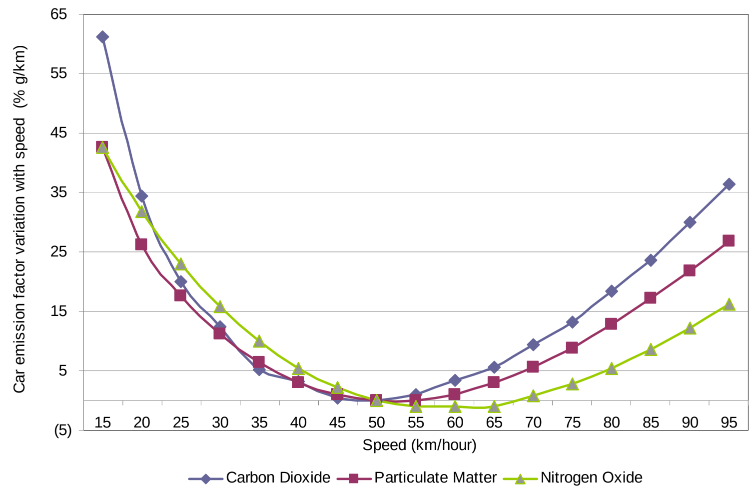
57. Technological improvement offers solution in reducing the carbon emissions. Appendix 6 provides an analysis of the likely impact of improvement in technology, especially related to vehicles.

B. Local Pollution Reduction, Traffic Safety, and Carbon Dioxide Reduction are Correlated

58. **Air quality impacts are correlated to carbon dioxide emissions.** Political support for sustainable low carbon transportation initiatives is more easily won when compelling local goals—such as protecting the health of local residents and workers, improving community livability, and improving safety—are aligned and emphasized, rather than more abstract goals of energy security and climate protection. Corroborating the research literature,[36] this EKB analysis found that air quality impacts are highly correlated to CO_2 emissions and other public health benefits, such as improved traffic safety. Where projects provide CO_2 reductions, it is likely that the project will also improve air quality and reduce traffic fatalities. This is due to several fundamental factors. First, pollution of all types and accidents are a direct function of vehicle-km traveled, so measures that reduce traffic growth will tend to cut pollution of all types and to reduce accidents. Second, as Figure 7 shows, CO_2, particulate matter, and NO_x pollution all tend to decrease as traffic speed approaches the 40–60 km per hour (kph) range, and then increase again at higher speeds. Thus, measures that improve traffic conditions by reducing low-speed stop-and-go congestion, while not inducing excessive vehicle speeds, will also tend to cut all types of vehicle air pollution. During periods of construction, these relationships may be complex. Localized construction emissions of dust and fine particulates from heavy equipment or construction-induced congestion may cause significant local pollution. This may coincide with high temporal CO_2 emissions associated with construction.

[35] The EKB analysis quantified the passenger transport emissions from Metro Manila and found that these annual emissions will amount to 17 million tons CO_2 in the 2015 business-as-usual scenario.
[36] Footnote 8; M. Peden et al. 2004. *World Report on Road Traffic Injury Prevention*. World Health Organization Geneva; and M. Replogle and J. Balbus. 2005. Considering Cancer Risk in Transportation Decision-Making. *Environmental Manager, Journal of the American Waste Management Association*.

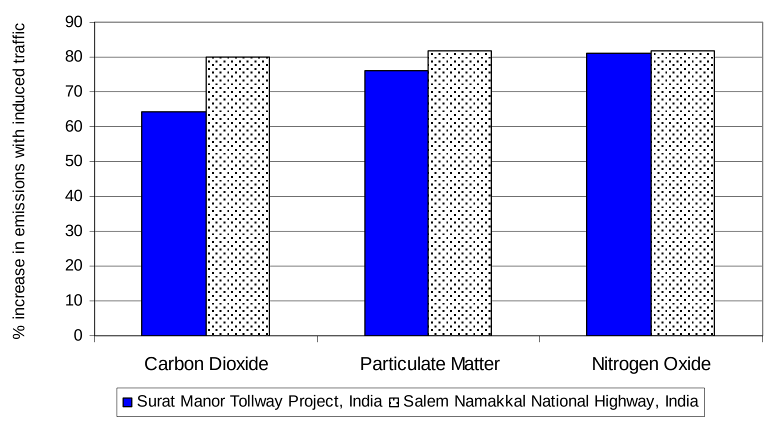
Figure 7: Impact of Speed on Vehicle Emissions



g = gram, km = kilometer.
Source: Independent Evaluation Department estimate based on empirical research.

59. This EKB analysis found that CO_2 and local air pollutant emission impacts moved in the same direction, with multiple interventions across many scenarios and project types. An evaluation of two expressway projects in India showed both producing growth in CO_2, particulate matter, and NO_x of 65%–80%, compared with a business-as-usual case (Figure 8). Across a range of assumptions for the likely effectiveness of modal diversion (from highly effective to ineffective), a BRT project in Manila was found to have CO_2 and local pollutant impacts moving in corresponding directions. A Philippine bikeway project was estimated to cut CO_2 by 30%, particulate matter by 4%, and NO_x by 6%.[37]

Figure 8: Correlation between Carbon Dioxide, Particular Matter, and Nitrogen Oxide



Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports from the National Highway Authority of India.

C. Construction Period Emissions

60. **Varied levels of construction emissions.** For transportation projects to minimize their carbon emissions, it is important to consider both construction and operations emissions. Road construction and maintenance in the total life cycle of roads usually constitute only about 5% of

[37] These figures are based on IED estimates drawn from the Marikina Bikeways Project funded by GEF.

total life cycle emissions.[38] Construction emissions typically represent anywhere from a few months to several years of operational emissions for rural roads and high-speed expressways, which typically have a life of about 20 years. Thus, while there are opportunities to reduce CO_2 in transportation through greener construction techniques and materials, the biggest savings potential is on the operations side. The same is true for BRT projects, where construction typically consists of building roadways suitable for heavy bus traffic plus station and access structures. However, projects that operate mostly in tunnels or on elevated structure, such as MRTs and urban elevated or underground expressways, typically require more concrete, steel, and excavation, which translate into greater embedded energy. For such projects, it may take years before the cumulative operational CO_2 emissions equal the initial construction emissions. The combined operational and construction emission associated with a high quality MRT will over time be more than fully offset by emission reductions as a result of mode shifting, induced transit-oriented development, and carbon-reducing impacts on urban form that increase walking, cycling, public transport use, and average trip lengths. However, a poorly designed and operated MRT may never achieve carbon neutrality.

61. A study of the Cairo subway project found that construction emissions may equal 28 years of operations emissions, considering fuel usage for construction machinery and embedded carbon content of primary construction materials.[39] Another study of the Bangalore Metro Rail Corporation, which considered only embedded carbon content of construction materials such as steel, cement, and asphalt estimated 15,655 tons of construction CO_2 emissions per km.[40] It shows that the construction emissions account for 28% of the overall emissions for the Bangalore Metro project with the remaining coming from operations emissions.[41] Similarly, an analysis of the proposed Ho Chi Minh City Metro (Line 2) over a 20-year project cycle shows that the construction emissions are a substantial portion of the life cycle emissions when considered on the entire length of the MRT. In this case, the construction emissions were found to be 20% of the total (construction + operations) emissions over a 20-year project cycle.[42]

62. **Construction emissions from roads and highway vary by facility type.** Low speed and low traffic state highways typically have relatively low construction CO_2 emissions. Higher level national highways that are designed for extensive truck and long-distance traffic will have deeper pavements, more extensive earthworks, greater use of bridging and cut-and-fill structures, super-elevation, and interchanges. All of these will tend to increase the carbon footprint of the infrastructure construction. The TEEMP analyzes projects based on the quantity of three key construction materials used—cement, steel, and bitumen.

63. **Railway construction emissions are comparable to those for two-lane roads.** Life cycle analysis research for a four-lane highway in the Republic of Korea has found that CO_2 emissions related to road materials are 57% of the total 20-year life cycle nonoperating emissions and construction activity accounts for only 2% of these emissions. For the same highway, maintenance and repair account for 40% of 20-year lifecycle nonoperating emissions

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[38] European Asphalt Pavement Association and European Bitumen Association. 2004. *Environmental Impacts and Fuel Efficiency of Road Pavements, Industry Report*. Brussels.

[39] Cairo subway has been analyzed for 30-year life carbon emissions. Source: Presentation by O. Grandvoinet and C. Bernadac from Agence Française de Développement on Carbon Footprint Methodologies for Development Projects and Case Studies. 2009. Practitioners' Network for European Development Cooperation. Brussels (March).

[40] IED forecast estimates using data from the Bangalore Metro Project, which is under construction by Bangalore Metro Rail Corporation. Data accessed from http://bmrc.co.in on 14 May 2010.

[41] This project was not funded by ADB but it provides a case study to identify the amount of construction emissions.

[42] MVA Asia. 2008. *Feasibility Report of Ho Chi Minh City Metro (Line 2) Project*. Ha Noi and Hong Kong.

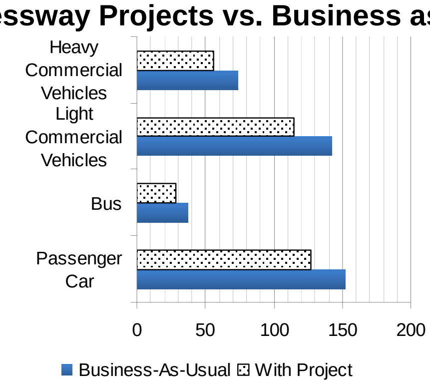
and demolition for only 1% of these emissions.[43] This suggests the use of a 1.75 multiplier on the construction material inputs values to calculate 20-year full life cycle construction and maintenance emissions. This multiplier has been adopted in this EKB for estimating railway construction CO_2 impacts to include embodied carbon. Inputs for measuring railway construction emissions are the number of rails per km, the number of sleepers per km, the number of fish plates per km of track, the number of fish bolts per km of track, the number of bearing plates per km of track, and number of dog-spikes per km of track. Quantity of ballast required for broad gauge initial analysis in the EKB has indicated that the construction emissions constitute nearly 5% of total emissions. Taking into account the above sources, construction emissions for railways have been estimated about 875 tons of CO_2 emissions per track-km of railway.

D. Operations Period

1. Non-Urban Transport Subsector

64. **Expressways moderate emission rates per vehicle-kilometer traveled from business-as-usual scenario.** As they can deliver higher speed and smoother traffic flow when operated efficiently, emission rates per vehicle-km traveled for expressways are lower than for smaller, slower roads for both light duty and heavy-duty vehicles (Figure 9). However, as data in Table 2 indicate, the overall emission rates per km of expressways tend to be higher owing to the relatively higher volume of traffic compared with rural roads and other smaller highways. Yet, from an energy and CO_2 perspective, the situation is worsened since investment in expressways tends to induce considerable new traffic and to orient new economic development in lower-density dispersed patterns that are more carbon-intensive for both transport and buildings. The induced traffic spurred by new expressway investments typically overwhelms the short-term CO_2 reduction that may be produced when new road capacity temporarily relieves traffic congestion in a corridor. Rural roads tend to carry lower levels of traffic and have relatively smaller induced traffic impacts. Railway improvements and new public transport services produce CO_2 emissions, but to the degree that they divert trips from more carbon-intensive modes of transport such as private motor vehicles, they typically reduce emissions in the long run. However, this is highly variable and depends on the efficiency of the railway public transport operation and the carbon intensity of the infrastructure needed to support the public transport service. If buses or trains have a high level of capacity underutilization, they can be more CO_2 intensive than private vehicles.

Figure 9: Emission Rate (grams per vehicle-kilometer traveled)
Expressway Projects vs. Business as Usual

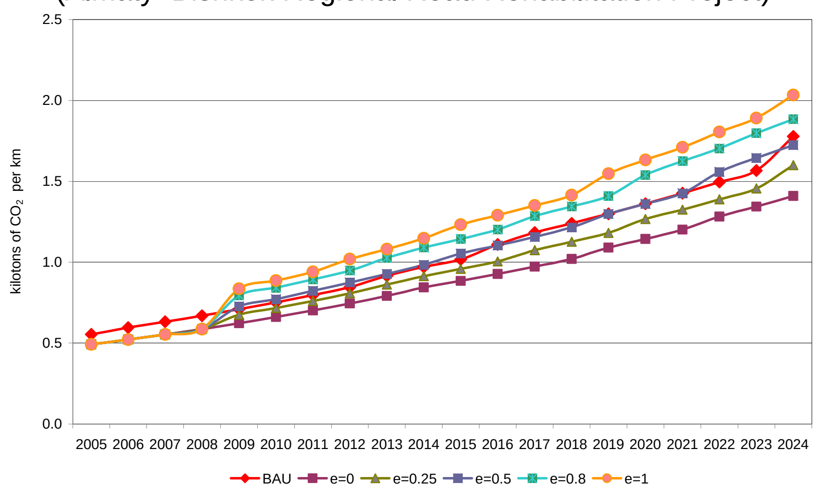


Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports.

[43] P. Kwangho et al. 2003. Quantitative Assessment of Environmental Impacts on Life Cycle of Highways. *Journal of Construction Engineering and Management*. 129. pp. 25–31. In addition, the estimation of railway construction emissions is based on discussions between the IED consultants and Mr Prashant Mutalik, independent consultant, India.

65. **Induced traffic effects boost CO_2 emissions from added road capacity typically by one-fifth to one-half or more.** Roads are often constructed because they tend to spur traffic, and this is often equated with economic development. An increase in traffic speed reduces the cost of mobility, thereby attracting more traffic. Researchers globally have found lane-km to have a statistically significant relationship with vehicle kilometers of travel (VKT),[44] with elasticity ranging from 0.5 to 1.0 or slightly higher.[45] The strength of this relationship across countries and data sets over time has led some to suggest a "law of road congestion: adding road capacity will not alleviate congestion on any sort of major urban road or rural highway within metropolitan boundaries."[46] This effect may be less pronounced for long-distance highways. The TEEMP has been designed to be sensitive to such elasticity in estimating the impact of new capacity on traffic and CO_2 emissions. Using the TEEMP to evaluate a typical national highway shows that CO_2 emissions for a typical national highway are 17%–58% higher when induced traffic is appropriately accounted for at an elasticity ranging from 0.25 to 1.0 in three different corridors. Figure 10 illustrates how induced traffic can affect CO_2 emissions for a typical national highway. Appendix 7 provides further details on the impact of induced traffic.

Figure 10: Impact of Induced Traffic on Carbon Dioxide Emissions
(Almaty–Bishkek Regional Road Rehabilitation Project)



BAU = business as usual, CO_2 = carbon dioxide, e = elasticity of traffic with regard to road capacity, km = kilometer.
Source: Independent Evaluation Department estimates based on Asian Development Bank. 2007. *Completion Report: Almaty–Bishkek Regional Road Rehabilitation Project in Kazakhstan and Kyrgyz Republic*. Manila; and Asian Development Bank. 2009. *Project Performance Evaluation Report: Almaty–Bishkek Regional Road Rehabilitation Project*. Manila.

66. **Elasticity assumptions impact induced traffic estimates.** Induced traffic needs to be included for CO_2 emissions quantification using appropriate elasticities. Low elasticity values (e.g., 0.25) are appropriate in rural areas where there is little repressed demand for motor vehicle travel, limited local motor vehicle ownership or growth in motor vehicle ownership, and where transport costs remain high relative to incomes even after provision of new road capacity. High elasticity values (e.g., 0.8 to 1.0) are appropriate in or near metropolitan areas, where the new capacity brings about a significant lowering of transport costs (in time and money), where

[44] R. Noland. 2001. *Relationships between Highway Capacity and Induced Vehicle Travel*. Transportation Research A, 35(1):47–72.
[45] An elasticity of 1 indicates that a 10% increase in lane capacity would result in a 10% increase in volume. This traffic is assumed to increase from the 5th year onward.
[46] G. Duranton and M. Turner. 2009. *The Fundamental Law of Road Congestion: Evidence from US Cities*. University of Toronto Department of Economics. http://individual.utoronto.ca/gilles/Papers/Law.pdf

motorization or urbanization is occurring at a rapid pace, and in areas of significant traffic congestion. Standardized elasticity assumptions may be established as part of ADB project analysis procedures to ensure consistency in analysis.

67. **Road maintenance projects can significantly reduce carbon emissions.** In recent years, ADB has funded road maintenance projects, i.e., periodic maintenance that involves surface and roughness improvement elements, which reduce road user costs, discomfort, pollution, and travel time. Good road maintenance also assists pedestrians and bicyclists. Road roughness is an expression of surface irregularity and affects ride quality and fuel consumption. This EKB has confirmed that a rough road slows down traffic and reduces efficiency, increasing fuel use and CO_2 emissions by 5%–10% or more.[47] In other words, periodic maintenance projects have a major impact on carbon emissions reductions.

68. Road maintenance improvement projects can potentially alter the emission profile of vehicles. This leads to a reduction in local pollution as well as a decrease in road user costs. The EKB analysis found that the emissions (CO_2 tons/km/year) increased by 1.6% when the road roughness increased from 2 meters (m) per km to 4 m/km. When the road roughness increased to 6 m/km, the emissions increased by 3.3%; and when the road roughness increased to 9 m/km, the emissions increased by 5.8%. This implies that if road roughness is limited to 3 m/km or lower with periodic maintenance, the intensity of carbon emissions could be controlled. This provides a new rationale for road maintenance projects.

69. **Carbon intensity of rail freight operations is less than carbon intensity of road freight operations.** There are numerous studies showing that rail-based freight haulage is more energy efficient and has lower CO_2 emissions than freight carried by road on trucks. This is a function of engineering science, as the rolling resistance of steel wheels on steel rail is considerably less than rubber tires on either flexible or rigid pavements. Railway trains also have the advantage of lower wind resistance as a single large, long train moves through space with one slipstream. Trucks are shorter, so each must overcome wind resistance alone. However, the positive aspects of railways have to be tempered with an analysis of their economic viability and integration with other modes of transport. Water transport is similarly more energy and CO_2 efficient than rail, as it takes less energy to overcome the resistance of moving a boat through water carrying a load than it takes to overcome the rolling resistance of moving the same load on steel wheels on steel rail. Moreover, the higher the speed of transport, the more energy is required to move a load, as the resistance that must be overcome moving through a gaseous or atmospheric fluid is an exponential of the speed.

70. The CO_2 and energy characteristics of a specific freight or passenger mode are highly dependent on many discrete factors that vary depending on local circumstances. The load factor or occupancy of vehicles is a key element determining CO_2 or energy efficiency and can be influenced by many things from changes in capacity and price to changes in the freight industry structure. For example, the PRC's trucking industry is less energy and CO_2 efficient than it could be because there is a nearly 1:1 ratio of truck trailers to truck tractors in the PRC, whereas in many other countries there are two or three times as many trailers as tractors. This gives the PRC truckers fewer opportunities to avoid empty back-hauls without a load, also known as "deadheading."[48] The application of a new emission and distance-based road use fee for heavy trucks operating on 12,000 km of high speed roads in Germany since 2005 reduced truck-km driven by 7% almost entirely as a result of reduced deadheading and likely producing a

[47] To ensure sound CO_2 impact estimation, actual travel speeds and road roughness should be measured, monitored, and forecast as part of comprehensive road traffic CO_2 emission abatement, as roughness affects traffic speed which, in turn, affects emissions.
[48] M. Parkash. 2009. *Promoting Environmentally Sustainable Transport in the People's Republic of China*. Manila: ADB.

corresponding boost to average system CO_2 efficiency. The 50% fee premium for older, more polluting trucks also doubled the rate at which older and polluting vehicles were replaced by newer, less polluting ones.[49] Higher energy consumption and CO_2 emissions per km tend to be associated with freight haulage through mountainous terrain rather than over flat ground because of greater braking energy losses.

71. In general, the core market for ship and rail freight services is the haulage of heavy bulk commodities, but both modes can also readily handle container freight. There is a general tendency for shippers to prefer the use of trucks and air freight for higher value container-based cargo since those modes have higher average speeds and reliability, and trucks have the capacity to reach more destinations. Although rail- or water-based freight transport may be more efficient, they serve far fewer destinations than truck-based transport. For many types of shipments, intermodal freight services, involving some combination of modes, are crucial for enabling CO_2 efficiency.

72. The EKB confirmed the widely acknowledged fact that rail freight is less carbon intensive than freight transported by road. Comparisons between railway projects and hypothetical parallel road projects support this finding. Emissions of railway projects were compared against a scenario of what would have occurred had the same freight traffic been carried by truck on typical partial access controlled highways. The analysis disregarded the impact of future efficiency improvements in both highways and railways.[50] Analysis of scenarios for three corridors in different Asian countries using the TEEMP found that shifting freight to road-based truck transport from rail would produce significantly higher CO_2 emissions. Shifting a portion of freight from truck to rail will reduce CO_2 emissions. Results of evaluating several selected corridors for the effect of shifting traffic between rail and road passenger transport were sensitive to assumed vehicle occupancy, corridor travel characteristics, and such other factors.

2. Integrated Supply and Demand Management for Non-Urban and Urban Areas

73. **Importance of integrated transport supply and demand management.** Traffic congestion affects economic development. It wastes time, fuel, money, and resources in addition to generating excess CO_2, which is bad for the environment. However, simply expanding the supply of roads and highways does not solve these problems; instead, it usually exacerbates them in the long run. Efficient modernization of transport succeeds best in both non-urban and urban areas, with integrated approaches that include a strong focus on travel demand and traffic management, rather than transport supply-focused strategies. This also requires attention to how different types of improvements affect the amount and share of regional travel by different modes at different speed ranges, which is fundamental to evaluating transport system efficiency, CO_2, and energy use.

74. The most cost-effective transport development modernizes in ways that improve mobility while supporting other broad goals, such as energy security, public health, CO_2 emissions management, and safety—integrating system management and operations with new capacity development. Pricing road capacity or improving parallel low carbon travel choices can partly or fully offset adverse CO_2 impacts of road capacity expansion. Revenues from transport pricing

[49] A. Kossak. 2006. Presentation on *Road Pricing in Germany*. Transportation Research Board Annual Meeting. Washington, DC.

[50] Research indicates that the efficiency improvements can play an important role in reducing carbon emissions from highways and railways. Such improvements include fuel economy and occupancy/loading improvements.

can be used to support better public transport, walking, cycling, traffic management, and user-side subsidies to offset any adverse equity impacts.[51]

75. In the absence of an integrated transport development plan, higher traffic speeds brought about by merely expanding road capacity do not produce carbon emissions reductions even in the short term. Among road projects examined in greater depth, the EKB found that only two out of five cases witnessed a decrease in carbon emissions over the first 5 years of project operations, excluding induced traffic effects. When new road capacity is created that promotes traffic speeds higher than 70 kph from a business-as-usual speed of 45 kph–60 kph, this may boost even short-term CO_2 emissions. Expanding high-speed road capacity is more likely to increase CO_2 emissions, even in the short term, while expanding moderate traffic speed road capacity is less likely to increase short-term CO_2 emissions and may help cut emissions in the short run.

76. **Induced travel is a key factor in integrated transportation system management.** Many ADB transportation project analyses assume that traffic will grow following general trends into the foreseeable future regardless of transportation policies and investments. This has been characterized as "predict-and-provide planning."[52] This assumption reduces the integrity of both economic and environmental analyses during appraisal. In moving to evaluate the carbon emissions impacts of transport sector operations, ADB needs to reexamine the acceptability of this methodological approach and take on board current global transport practices.[53] ADB appraisals need to recognize that traffic grows to fill the space allotted to it, and similarly, traffic growth slows in the face of less ample provision of road space, traffic policies designed to slow and calm traffic, and higher road user and parking charges.[54] The World Bank and the University of Leeds have designed a toolkit to integrate consideration of induced traffic in user benefit estimation.[55]

77. **Traffic demand is sensitive to congestion limits.** This EKB has built on good practice approaches by recognizing that emissions from roads carrying a high intensity of traffic are highly sensitive to the saturation limits of V–C ratios. It is incorrect to assume that roads can always accommodate increasing traffic volume without increases in capacity, which has been a common assumption in several ADB project appraisals to date. Many corridors show some kind of saturation after the V–C ratio exceeds 1.0 as an increasing number of travelers change their destination choice, mode of travel, route, or time of day of travel, or decide not to travel at all.

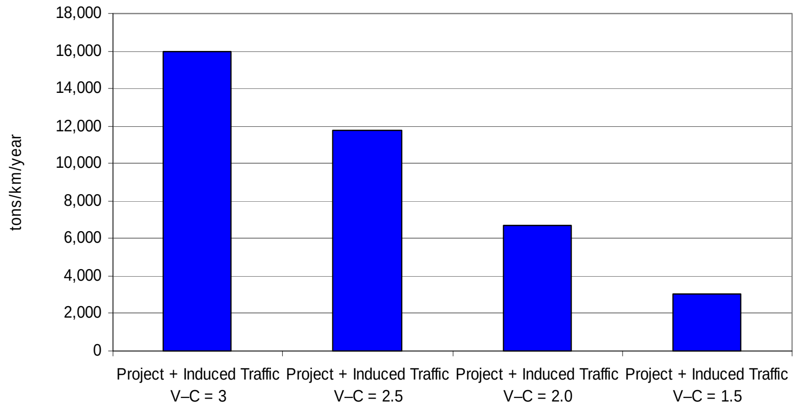
78. Economic and environmental analysts need to make appropriate assumptions about the maximum corridor saturation factor, as this can significantly change the forecast for future CO_2 emissions and user benefits. While peak spreading can enable peak-period V–C ratios as high as 2, it is unrealistic to assume that most corridors will sustain V–C ratios exceeding 2 on a routine basis, as travelers pursue other choices to avoid excessive congestion delays.

79. To evaluate how saturation affects CO_2 emissions estimates in the TEEMP, multiple corridors were tested assuming different traffic saturation caps, here expressed as varying V–C ratios. For high volume roads, such as Surat Manor in India, the assumption of a saturation limit has a major impact on estimated CO_2 emissions (Figure 11). For such high volume roads, it is

[51] D. Lewis. 2008. America's Traffic Congestion Problem: Toward a Framework for Nationwide Reform. *Discussion Paper 2008–06*. Washington, DC. Brookings Institution, The Hamilton Project (July).
[52] Culture Change. *Predict and Provide Planning is a Dead End*. http://culturechange.org/issue8/predict%20and%20provide.htm (accessed 27 May 2010).
[53] S. Owens. 1995. "From 'predict and provide' to 'predict and prevent'?: Pricing and planning in transport policy." *Transport Policy*. 2(1). pp. 43–49 (January).
[54] Various sources. Main articles listed on http://www.moderntransit.org/links-induced.html (accessed 27 May 2010).
[55] P. Mackie, J. Nellthorp, and J. Laird. 2003. Treatment of Induced Traffic. *Toolkit for the Economic Evaluation of World Bank Transport Projects*. Institute for Transport Studies, University of Leeds. http://www.its.leeds.ac.uk/projects/WBToolkit/Note6.htm

important to take into account traffic saturation effects when evaluating a road expansion project. When a road has reached its saturation, this will limit further traffic growth and reduce the CO_2 emissions under the business-as-usual scenario. In this case, capacity expansion will unleash greater induced traffic and related CO_2 growth. The TEEMP has been designed to take this into account.

Figure 11: Impact of Carbon Dioxide Emissions Traffic Saturation on High Volume Highways



km = kilometer, V–C = volume to capacity.

Source: Independent Evaluation Department analysis based on data from Surat–Manor Highway obtained from the National Highways Authority of India and ADB. 2007. *Completion Report: Surat–Manor Tollway Project in India*. Manila.

80. **Accurate speed estimates and forecasts are critical to emissions estimation.** To evaluate CO_2 emissions, it is important to account for the effects of transportation projects on vehicle speeds, which in turn are affected by the V–C ratio of facilities and the assumed maximum traffic saturation factor. Fuel consumption and air pollutant emission factors as a function of speed were derived by the TEEMP using various studies. Many studies have established that vehicles traveling near 50 kph have the best efficiency, so speed was used as an anchor to compute the decrease in efficiency. This enables a simplification of emissions modeling while providing sensitivity to the impacts of design speeds and congested speeds of travel. Figure 8 shows the impact of induced traffic on emission intensity factors for three pollutants in the TEEMP.[56] The impact of speed on air pollutants follows similar logic.

81. **Braess's paradox: adding road capacity can cause congestion.** A well-documented phenomenon known as "Braess's paradox"[57] states that adding a new link to a transport network more often than not causes increased road congestion, rather than reduced congestion.[58] There are a number of real world examples of this. In Seoul, the Republic of Korea, after the Cheonggyecheon freeway was removed from the central city, traffic speeds around the city were observed to increase.[59] Additions to the road network in Stuttgart, Germany in 1969 provided no benefit to the traffic situation until a section of newly built road was closed to traffic when speeds increased.[60] In 1990, the closing of 42nd street in New York City reduced the amount of congestion in the area.[61] The recent closing of large sections of

[56] It shows the percentage increase in emissions (i.e., negative value is used to describe increase in emissions).
[57] Translation of the Braess 1968 article from German to English appears as the article "On a paradox of traffic planning," by D. Braess, A. Nagurney, and T. Wakolbinger. 2005. *Transportation Science*. 39. pp. 446–450.
[58] R. Steinberg and W.I. Zangwill. 1983. The Prevalence of Braess's Paradox. *Transportation Science*. 17 (No. 3). pp. 301–318.
[59] D. Easley and J. Kleinberg. 2008. *Networks*. Cornell Store Press. p. 71.
[60] W. Knödel. 1969. *Graphentheoretische Methoden und ihre Anwendungen*. Springer-Verlag. pp. 57–59.
[61] G. Kolata. 1990. What if they Closed 42d Street and Nobody Noticed? *New York Times*. 25 December.

Broadway in New York City similarly produced some congestion relief and faster overall speeds for taxis in Manhattan.[62]

82. In view of this, project developers should not assume that increasing road capacity will always lead to CO_2 decreases or related reduction in fuel consumption, pollution, or congestion in the absence of strong mitigation measures, such as road user charging or provision of substantially improved public transport services and improvements to the pedestrian and bicycle environment in the corridor. Sustainable low carbon transportation strategies require careful balancing of investments in different travel modes; policies to manage traffic, public transport services, and street space; coordination with urban development policies; and appropriate pricing of mobility options.

83. **Smart traffic management can cut carbon emissions by about 20%.** The EKB analysis validated the findings from the research literature that CO_2 emissions can be cut by about 20% by techniques to mitigate congestion, manage speed, and smooth traffic flow. The effects will be even greater for heavy-duty trucks, which tend to have much lower power–weight ratios than cars. Even small changes in speed can yield a significant reduction in congestion, pollution, and energy use. This argues for integrated urban and corridor investment and operations management strategies, rather than isolated investments in new roads, railways, or public transportation facilities. Box 2 summarizes the traffic management options for reducing carbon emissions.

Box 2: Traffic Management

Three ways to manage car speeds for reducing carbon dioxide emissions are as follows:
(i) reduce car speeds from very high levels to about 50 kilometers per hour,
(ii) reduce stop-and-start traffic by smoothing traffic flows, and
(iii) increase car speeds from very low levels up to 50 kilometers per hour.

For each of these methods, effects on induced traffic and other travel modes need to be considered. For example, faster, smooth traffic can also divert trips from public transport, walking, or cycling unless these modes are given priority access to street space or unless car use is priced appropriately with parking or road user fees. The optimum speeds for heavy goods vehicles will be lower as compared to those for cars.

Source: Independent Evaluation Department.

84. Mitigation techniques to obtain these CO_2 reduction benefits include the following:[63]

(i) **Congestion mitigation strategies.** These strategies focus on increasing average traffic speeds up to 50 kph from slower speeds. Examples include ramp metering; enhanced traffic incident and operations management; and such travel demand management techniques as parking pricing, street space reallocation, company car management, congestion pricing, and auto use restrictions. Where buses make up a significant share of traffic, it includes designing high quality BRT systems to speed bus traffic, replacing many smaller inefficient buses with fewer high-capacity buses, designing BRT stations for rapid boarding and so that buses and cross-traffic at intersections do not impede each other.

(ii) **Speed management techniques.** These reduce high speeds to safe speeds. This can be accomplished by enforcement by police, radar, or cameras, or through voluntary measures, such as commercial vehicle operator training for

[62] M. Grynbaum. 2010. New York Traffic Experiment Gets Permanent Run. *New York Times*. 11 February.
[63] M. Barth and K. Boriboonsomsin. 2008. Real-World CO_2 Impacts of Traffic Congestion. *Transportation Research Record*. 2058. http://trb.metapress.com/content/n622635366032635/ (accessed 27 May 2010).

eco-driving and fleet operator driver behavior monitoring systems. Emerging effective technologies include active accelerator pedal and intelligent speed adaptation where top speeds are capped based on specific traffic conditions. Reducing higher speed traffic to 50 kph will reduce CO_2 emissions. Even modest reductions in expressway speeds from speeds higher than 80 kph can reduce CO_2 emissions and fuel use.

(iii) **Traffic flow smoothing techniques.** These seek to curb stop-and-go traffic, suppressing shock waves, and reducing the number and severity of accelerations and decelerations. This can be achieved through the use of variable speed limits on expressways and by installing computerized and coordinated traffic signal systems on arterial streets. It has been shown that intelligent speed adaptation can eliminate much of the stop-and-go effect during congested conditions, which results in 12% of CO_2 reduction. Eco-driving training, vehicle monitoring by fleet operators, and auto insurance pricing incentive programs[64] can contribute as well. The greatest CO_2 reduction benefits from smoother traffic flow are to be obtained in the 8 kph–55 kph speed range, where reductions in CO_2 per vehicle km traveled of one-third or more are possible (footnote 63).

85. Singapore has demonstrated for a metropolitan area how adjustments to the time-of-day pricing of roadways at various locations and times on an arterial and expressway network can be used to boost traffic speeds and support that city's goal of keeping traffic free flowing at least 85% of the time.[65] Other cities from London to Stockholm and Milan have had similar success on a smaller scale with congestion pricing. The Washington State Department of Transportation and others have found that up to half of the throughput capacity of expressways is lost during peak hours as a result of stop-and-go congestion. By using congestion pricing, ramp metering, incident management, travel demand management, improved public transportation, and other strategies, transportation agencies can recover this lost road capacity during times of peak demand when it is most needed, often at a far lower cost than building added road capacity. By employing more active transportation system management techniques, infrastructure operators typically also reduce their carbon footprint and expand travel options for their customers. The privately run A1, Autoroute du Nord toll road north of Paris, France has since 1992 used time-of-day congestion pricing on long-distance expressways to manage weekend peak congestion.[66] The time-of-day Pier-Pass container fee program for the Ports of Los Angeles and Long Beach is helping to shift truck traffic to off-peak hours to cut congestion on expressways across southern California.[67]

86. **Road user charges can control carbon dioxide emissions of new and existing roads, while generating revenue that can be used to pay for other low carbon transport investments.** Congestion pricing of roadways can reduce CO_2 emissions if applied to existing road capacity, particularly if tolls are used to support better public transportation and traffic management. Where applied to new road capacity, tolls and congestion pricing will tend to diminish the induced traffic that causes CO_2 to increase. Congestion pricing will tend to reduce stop-and-go congestion that causes CO_2 to increase. But if toll revenues are used merely to build more highways, road user charging will tend to increase CO_2. Congestion pricing is not a

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[64] For example, the Progressive Auto Insurance "My Rate" program in the United States of America (USA) offers drivers a discount of up to 60% on car insurance rates if they drive fewer km and drive with fewer rapid accelerations and decelerations. These are monitored using an inexpensive device fitted to the vehicle's on-board computer and transmitting user data once a day to the company.

[65] Ministry of Transport. 2008. Speech by R. Lim (Singapore Minister for Transport) - *Ensuring Smooth Flowing Roads*. Singapore (30 January). http://app.mot.gov.sg/data/s_08_01_30.htm (accessed 27 May 2010).

[66] Tollroad News. 1997. FRANCE: North and East of Paris. 15 November. http://www.tollroadsnews.com/node/1859.

[67] See http://www.pierpass.org/Offpeak_About.htm.

cheap way to reduce CO_2, but can produce substantial co-benefits in time savings, mobility, and pollution reduction.[68]

87. **Automated toll collection systems are now practical and cost-effective, but require careful planning and capacity building to enable successful implementation.** Traditionally, tolls were collected manually at fixed tollbooths that required vehicles to stop and queue for payment. This creates a new source of CO_2 emissions related to stop-and-start traffic and queue delays. Toll collection, when possible, should be automated using toll transponders, automated license recognition, or satellite-based global positioning systems, as such systems are now practical and offer the potential for effective traffic management. The cost of implementing such modern road user charging on highways varies greatly depending on the technology used, the extent of coverage, enforcement mechanisms, and other factors. Successful implementation requires legal authority to implement and enforce automated road user charges, reasonably effective motor vehicle licensing and registration systems, back-office systems for license plate recognition or other enforcement and billing, installation of enforcement cameras and possibly transponder readers or satellite equipment, and possibly the equipping of vehicles with toll transponders or other billing and communication devices, depending on the technology employed.

88. **A toolkit of additional transport and logistics management strategies can cut carbon dioxide from transportation.** A variety of other strategies can enable cities, provincial and state authorities, and nations to improve traffic operations, transportation management, and pricing, boosting the efficiency of roads of all types while reducing CO_2 emissions. Some additional approaches that are cost-effective include pay-as-you-drive insurance, which if universally available, can reduce CO_2 by 6%–15% by ensuring that the cost of vehicle insurance is closely tied to the number of km driven, rather than priced by the year. Pay-as-you-drive policies are based on the same rating factors as other insurance, such as driving records and the type of vehicle driven, but enable the consumer to save by driving less and in some cases by driving less aggressively.[69] In addition, information and communications technologies offer potential to enable social networking and other collaboration tools to facilitate car-sharing and carpooling; provide real-time information on bus routes, availability, and waiting time; support smart parking management and pricing; and provide drivers with real-time feedback on fuel economy, enabling CO_2 savings through eco-driving. In the coming decades, the growing use of information and communications equipment as standard elements in motor vehicles across the world is likely to support a diverse array of mobility, safety, consumer, business, and billing services. Such equipment will sharply reduce the cost of real-time transportation facility and network operations management, including automated dynamic road pricing to keep traffic flowing smoothly and pay-as-you-drive motor vehicle insurance. Such features as vehicle-to-vehicle communications are likely to support smart adaptive cruise control, which could enable higher vehicle throughput on limited access facilities with automated speed limit control to prevent excessive speeding and sharply reduce the onset of stop-and-go congestion.

[68] J. Eliasson. 2010. *So You're Considering Introducing Congestion Charging: Here's What You Need to Know—An FAQ Based On Stockholm's Experience*. Discussion paper presented at the International Transport Forum, Organisation for Economic Co-operation and Development Round Table Meeting, 4–5 February on Implementing Congestion Charging. International Transport Forum. Paris.

[69] This insurance pricing system is offered in a dozen states in the USA by Progressive Insurance Corporation under the trademarked name "My Rate." Other companies are beginning to offer pay-as-you-drive insurance pricing in various countries, including Australia, Israel, South Africa, and the United Kingdom. A study by Brookings Institution in 2008 estimated that universal provision of pay-as-you-drive insurance in the USA would cut vehicle km traveled and related GHG emissions by 8% while cutting accidents and fatalities, producing social benefits of $30 billion a year, and save two-thirds of households on their car insurance, with the average savings for these households amounting to $270 per vehicle per year. Source: Bordoff, Jason E. and Pascal J. Noel. 2008. *Pay-As-You-Drive Auto Insurance: A Simple Way to Reduce Driving-Related Harms and Increase Equity. Hamilton Project Discussion Paper 2008-09*. The Hamilton Project. Washington, DC.

89. **Smarter supply chains and logistics management offer new freight carbon dioxide reduction opportunities.** In the freight sector, there is a significant potential for reducing CO_2 through smarter supply chains and logistics management. Companies like DHL and IBM are already advanced in exploring this for their clients. Measures can be as simple as finding ways to encourage a reduction in the number of empty back-hauls by trucks or as sophisticated as the adoption of more widespread automated road pricing. Timely progress in achieving the potential reductions in emissions will require much better information and communications systems to be embedded in transportation systems system-wide, enabling a further reduction in warehousing, a shift to lower carbon modes of freight, a shift from emphasizing speed of delivery to emphasizing reliability and predictability in delivery, and other elements. ADB and its member governments have a key role to play in helping to facilitate this transformation of global goods movement and delivery services and to further dematerializing global manufacturing and shipping.[70] Modernization is likely to increasingly embody these trends, as information and services occupy a growing share of global economic activity and as new technologies facilitate more customized manufacturing, with less packaging, more and more blurring the lines between material products and services. The potential economic return on investment and the potential CO_2 reduction are both huge. The TEEMP does not yet have a freight systems element to deal with such broader economic trends, but such freight and logistical components could be developed in the future.

90. **Travel demand management and real-time operations management boost the emissions reduction potential of public transport.** If public transport projects do not provide a good level of service that can offer attractive travel speed and reliability, they are likely to exacerbate the decline of public transport use in cities undergoing rapid motorization and may produce few or even negative CO_2 benefits. The same public transport investment can generate far higher CO_2 reduction if improved public transport is supported by travel demand management, parking or road use pricing, improved conditions for walking and cycling, traveler information systems, real-time road and public transport operations management, and incident management services.

91. The TEEMP can account for such supportive measures through best practice adjustment factors. Lessons from the Bangalore Metro project show that a good travel demand management yields 123% more CO_2 emission reduction as compared with the absence of such measures. However, a low level of shift to public transport has an opposite impact of increasing CO_2 emissions. A similar analysis for a transit corridor in Manila found that if as few as 20% of the motorized private and intermediate public transport (minibuses that are locally referred to as jeepneys) trips in a transit corridor were diverted to a new metro or BRT service, CO_2 emissions would increase.

3. Urban Transport Subsector

92. **Integrated urban planning initiatives offer substantial opportunities to reduce carbon footprint.** Urban areas across Asia are the places where transport CO_2 emissions are growing most quickly because of rapid motorization. Major urban road investments can be packaged with improvements to public transport, walking, and cycling, and transportation management and pricing strategies, as discussed above under smart traffic management.

93. A TEEMP analysis of the ADB-funded Lanzhou Sustainable Urban Transport Project, which includes constructing 34 km of urban roads, BRT facilities, and NMT lanes, showed that the overall project will increase CO_2 emissions because of induced demand spurred by new roads. However, if introduced with strong measures to manage traffic and improve average traffic speeds, such as congestion pricing or comprehensive parking management, the package will reduce CO_2 emissions.

[70] The Climate Group. 2008. *SMART 2020: Enabling the Low Carbon Economy in the Information Age*. http://www.smart2020.org/_assets/files/02_Smart2020Report.pdf

By combining multiple measures that reinforce each other to expand and enhance the attractiveness of low carbon sustainable travel choices, it is possible to produce considerable reductions in transport-related CO_2 while enhancing mobility, economic development, and equity of access to opportunities for low- and moderate-income individuals. Experience from cities like Bogotá (Colombia), Curitiba (Brazil), Singapore, and others in Europe, Japan, and the Republic of Korea shows that for maximal success in decoupling traffic growth from economic growth, it is important to eliminate both visible and hidden subsidies for driving and encourage more efficient spatial planning and land development patterns (paras. 102–109 detail the cost-effectiveness of various modes).

94. **Mode shift to public transport can reduce emissions significantly.** Investment in well-designed and operated public transportation can be an effective way to cut CO_2 emissions. Trains and buses have the capacity to carry more passengers in a single high efficiency vehicle compared to private cars. As long as the occupancy of public transport vehicles is high, their CO_2 per passenger-km will tend to be much lower than for private motor vehicles. Public transport investment offers potential to spur and anchor higher density mixed-use developments where a larger share of trips can be made over short distances on foot or by bicycle. Public transportation investment reduces CO_2 emissions when it cuts average trip lengths (avoiding unnecessary travel); spurs more walking, cycling, and high efficiency public transport use (shifting trips to low carbon modes); and supports greater amounts of urban development in GHG efficient forms (with buildings that support higher efficiency of heating, cooling, and overall energy use).[71]

95. **Effectiveness of public transport investment depends on many factors.** Not all public transport investment has the same potential to reduce CO_2 emissions. Poorly designed investments, which shift few trips away from higher carbon modes of transport may cost more in embedded GHGs to build than they reduce over their lifetime of operations. Poorly operated services may produce higher CO_2 emissions per passenger-km than competing private motor vehicle transportation. To support this hypothesis, the TEEMP calculated the projected number of passengers on a proposed BRT or MRT system, estimated the CO_2 emissions of the new system, and compared the CO_2 that these passenger trips would have generated if they were still using their old modes to make the same trip. A key assumption is the estimate of what share of trips using a proposed new BRT or MRT will have been drawn from other competing modes of travel and the CO_2 emission characteristics of those former modes of travel. The degree to which a BRT or MRT will compete successfully against other modes is a function of the characteristics of the public transport service offered, such as speed and convenience. The TEEMP also evaluates the CO_2 emissions of the BRT or MRT service based on such factors as fuel used, vehicle occupancy, and speed. The model is sensitive to the composition of the vehicle fleet in use in a corridor and the markets from which public transport passengers for new services are drawn, as well as the efficiency of the new public transport services. A major factor is also whether the BRT or MRT trips substitute the vehicle trips used as the prior mode of travel, or whether the new BRT or MRT trips are additive to the prior travel. These assumptions need to be established at the appraisal stage to increase the robustness of TEEMP applications.

96. **Metro rail transit and bus rapid transit have similar emission savings for similar system length.** Whether BRT or MRT would reduce CO_2 emissions more in a given corridor depends on many factors specific to the context for implementation—the character of local traffic, trip making patterns, the way the public transport investment fits within the larger network, and many other elements. A key factor is whether the trips carried by the BRT or MRT are diverted from existing public transport, intermediate transport, walking, cycling, or driving. If

[71] The TEEMP accounts only for the transportation aspects of public transport CO_2 emissions impacts, not building impacts.

from driving, are the cars or motorcycles that would have been driven being left at home unused? On the other hand, are they in use by someone else? If the trips are diverted from former bus or paratransit trips, are those buses or paratransit vehicles still operating somewhere or have they been scrapped? If they are operating, what are the traffic conditions and levels of use? The TEEMP is designed to account for these interactions through calculations or appropriate user assumptions derived from project planning documents or models.

97. The effectiveness of a transit system will be a function of many factors, including overall travel speed, frequency of service, directness and ease of transfers, fare policy, access and egress conditions to and from stations or stops, and passenger security and comfort. MRT systems can provide high speed, directness, and capacity by running underground or on elevated structures, but at considerable cost and often entailing greater time spent in access, exit, and transfers. Well-designed BRT systems often provide more direct one-seat rides and can match MRT systems for other elements at a far lower cost if given priority access to surface street space. However, such access requires some political leadership to reallocate or manage street space consciously.

98. Based on the TEEMP, it was found that either BRT or MRT would produce roughly equal and large emission reductions if the public transport system is designed and implemented in a way that enables it to reduce a high share of VKT that was previously made by customers on the new services.[72] Appendix 3 includes a more in-depth review of how the TEEMP was applied to two corridors in Bangalore and Manila, evaluating equivalent length BRT and MRT corridor alternatives, producing this finding.

99. This finding does not change the importance of financial feasibility and political feasibility. The selection of an expensive MRT may sharply constrain the extent of service coverage and take years to put into place. The selection of a more cost-effective high capacity BRT may enable a much higher level of public transport service to a larger share of the potential transit market, given a fixed level of investment and operating support, and deliver improved transit service quality far sooner than for an MRT. Serving a larger share of the regional travel market with high quality competitive public transport services will yield greater CO_2 reductions over time. It may even attract added investment capital if stable opportunities are provided for such capital to earn a reasonable rate of return in the public transportation marketplace.

100. **Upgrading bikeways and sidewalks in projects provides large emission reduction.** The EKB analysis, supported by empirical research on non-ADB funded projects, confirmed that well-designed and operated NMT system investments can yield significant CO_2 reductions. When road investments provide few or no amenities for pedestrians and cyclists, they often degrade the environment for walking and cycling by reducing the street space for the modes, reducing the directness of NMT travel, and boosting the speed and volume of motor vehicles. This forces many people who had previously walked or cycled to switch to more costly, polluting, and CO_2 intensive means of transport, whether intermediate public transport, motorized two-wheelers, cars, buses, or MRT. This leads to a continuing decline of NMT in many cities worldwide, which is a major contributor to CO_2 emissions growth in the transport sector. However, building bikeways and sidewalks either as part of larger road, rail, or other public transport projects, or as separate projects, can help sustain or increase the share of trips by walking and cycling and reduce emissions and accidents.

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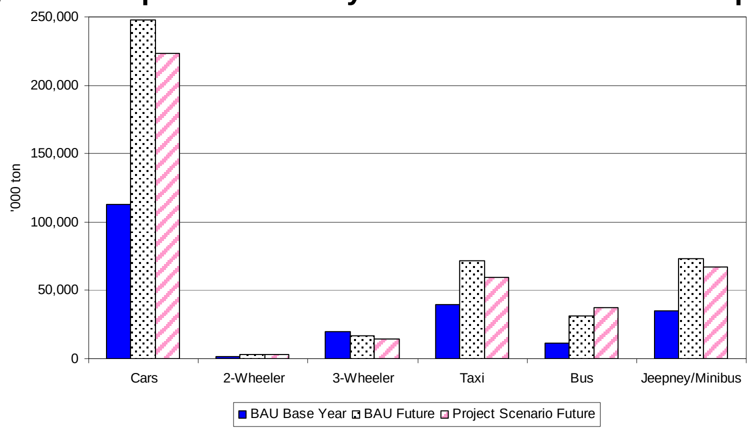
[72] This would be the result if BRT or MRT were implemented with the scrappage of a high share of the minibuses and buses that previously served their customers (which has been the case for many BRT systems, such as systems in Bogotá and Mexico City) and if car drivers attracted to the BRT or MRT system left their cars at home unused.

101. For example, a $1.5 million 66-km urban bikeways project in Marikina, Philippines (funded by the GEF) is estimated by the TEEMP to reduce CO_2 emissions from multiple other travel modes in the same travel corridors from a business-as-usual scenario (Figure 12). Emission reductions likely to occur in any specific project will be a function of other factors including the density of trip origins and destinations served by the project, the degree to which the project overcomes nearby barriers to walking and cycling, the connectivity of the project to existing pedestrian and bicycle networks and the quality of those networks, topography, climate, quality of project design, and cultural supportiveness of the city for walking and cycling.

Figure 12: Impact of Bikeways on Other Modes of Transport



BAU = business as usual.
Source: Independent Evaluation Department analysis based on data from the Marikina Bikeways Project.

4. Cost-Effectiveness of Urban Transport Projects

102. **Adding CO_2 mitigation measures to urban transport projects offers opportunities to improve the cost-effectiveness of mobility investments.** The capital cost of adding elements to ADB projects that will reduce their carbon footprint is small and is likely to improve the overall cost-effectiveness of mobility investments by ADB. In most cases, carbon-friendly transportation investments deliver personal mobility at a fraction of the cost of expressways, which have been the major focus of ADB transport spending in the past decade. While capital costs, throughput capacity, and street cross section of different types of urban transport facilities vary considerably depending on the local context and quality of design, implementation, and management, it is possible to illustrate these relationships with values typical for rapidly growing Asian cities.

103. Table 4 provides illustrative values, arraying in descending order based on the number of people that can be moved by different facility types in an hour for a given capital cost. It shows the cost-effectiveness of capacity by type based on these illustrative values. In this example, for the same $1 million in spending on new capacity, 20,000–24,000 people can move via bikeways and walkways, while expressways, BRT, and low-income area urban roads can move 4,500–5,665 people. Because roads in high-income urban areas have much lower average vehicle occupancy, the same spending on these will typically move only 2,600 people an hour. For metros and elevated rail, the same spending will move only 625–1,000 people in this example. Urban elevated expressways and underground expressways carry the fewest people per $1 million of capital spending, from 170 to 565. Of course, each of these modes has different qualities of speed, flexibility, user control, efficiency in use of limited surface transportation right-of-way, and operating cost. No one mode or investment type can meet all travel requirements in an urban area. However, a shift in investment priorities can yield changes in mobility patterns, the cost-effectiveness of mobility investments, and CO_2 emissions.

Table 4: Illustrative Capacity, Cost, and Street Cross Section for Various Urban Transport Facilities

Transport Mode	**Hourly Capacity to Move People per $1 Million Capital Cost** ($)	**Capacity** (person per hour per direction)	**Street Cross Section Used** (m)	**Capital Cost** ($ million per km)	**Capacity per Meter Cross Section** (persons per hour per meter cross section)
Footpath, 2 m wide	24,000	2,400	2	0.10	1,200
Bikeway, 3 m wide	20,000	3,000	3	0.15	1,000
Expressway, four-lane	5,665	8,500	20	1.5	425
BRT-high capacity	5,000	35,000	12	10	4,165
BRT-low capacity	4,500	6,000	8	3	2,250
Urban road, two-lane (low income)	4,500	4,500	9	1	500
Urban road, two-lane (high income)	2,600	2,600	9	1	290
Metro underground	1,000	60,000	na	60	na
Elevated rail	625	25,000	7	40	3,570
Urban elevated expressway, four-lane	565	8,500	7	15	1,215
Urban underground expressway, four-lane	170	8,500	na	50	na

BRT = bus rapid transit, km = kilometer, m = meter, na = not applicable.

Note: A range of values are possible depending on vehicle occupancy, system design and management, service characteristics, soil geology, and local construction costs.

Source: Independent Evaluation Department estimate based on empirical research.

104. **Combination of bus rapid transit, walking, and cycling offers high urban transport carbon dioxide mitigation potential while lowering costs of mobility.** It is important to consider efficiency in the use of scarce surface right-of-way for transportation, especially in dense urban areas where street space is at a premium and can often be expanded only by demolishing buildings or at the expense of public space. Modern BRT systems (modeled on Bogotá or Guangzhou) have the greatest efficiency in use of surface right-of-way (Table 4), combined with the highest cost-effectiveness of any public transport mode and moderate speed. BRT has the potential to serve longer-distance trips in urban areas with many more one-seat rides than MRT. Because a BRT system brings a high potential to induce mode shifting and improve overall traffic management in a corridor, it has enormous potential to reduce CO_2 emissions in urban areas. Modern BRT systems need good walking and bicycling access if they are to succeed in supporting transit-oriented development. Excess reliance on expressways and roads for urban mobility is a recipe for growing traffic congestion and a spiral of declining urban quality of life because of noise, pollution, and loss of urban public space. Investment in high quality BRT and rail transit, walking, and cycling, together with effective traffic management, can create an upward spiral that helps curb excess congestion and boost the quality of urban life.

105. **Findings consistent with recent international analysis by the Intergovernmental Panel on Climate Change (IPCC).** While walking and biking are slower and more suited for shorter trips of 3–10 km or less, they are inexpensive to provide, available to even the lowest income users, and are efficient in their use of surface transportation right-of-way. They provide high flexibility, equal to or greater than for private motorized transportation. The IPCC has concluded that walking, cycling, and BRT combined have the potential to reduce CO_2 from urban transport by one-fourth at a cost of $30 per ton of CO_2, while producing considerable mobility, public health, and other co-benefits (Table 5).

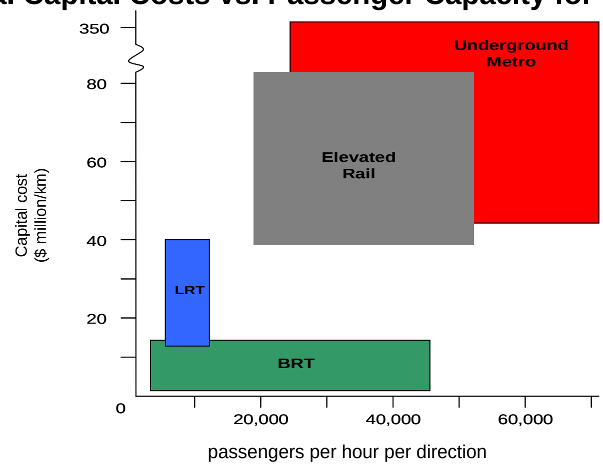
Table 5: Estimated Greenhouse Gas Reduction Potential and Cost per Ton

Transport Measure	**GHG Reduction Potential** (%)	**Cost per tCO_2e** ($)
BRT mode share increases from 0% to 5%	3.9	66
BRT mode share increases from 0% to 10%	8.6	59
Walking share increases from 20% to 25%	6.9	17
Bicycle share increases from 0% to 5%	3.9	15
Bicycle mode share increases from 1% to 10%	8.4	14
Package (BRT, pedestrian upgrades, bikeways)	25.1	30

BRT = bus rapid transit, GHG = greenhouse gas, tCO_2 = ton per carbon dioxide equivalent.
Sources: K. Ribeiro et al. 2007. Transport and its Infrastructure. In Climate Change. 2007. Mitigation. *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. B. Metz et al, eds. Cambridge University Press. Cambridge and New York. Citing L. Wright and L. Fulton. 2005. Climate Change Mitigation and Transport in Developing Nations. *Transport Reviews*. 25(6). pp. 671–717.

106. **Bus rapid transit has potential to provide wider service and CO_2 reduction with limited budget.** MRT systems offer higher capacity than most currently operating BRT systems because of various factors. MRT systems are mostly developed to run underground or on elevated structures. BRT systems mostly operate at the surface at a far lower expense, where their capacity and speed is a function of the degree to which they are given access to sufficient right-of-way to enable passing at stations, adequate platform length at stations, and priority at intersections. Securing conditions for optimal BRT system implementation requires political leadership, but less funding, meaning that BRT has the potential to provide more extensive high quality public transport services in a metropolitan area with a limited budget. A growing number of high capacity BRT systems—most notably the Bogotá, Columbia system developed since the late 1990s and Guangzhou, PRC, which opened in early 2010—offer capacities equal to MRT systems, carrying 25,000 to 35,000 or more passengers per hour past the peak load point per direction. Obtaining such capacity requires the full suite of elements shown in Table A3.9 in Appendix 3. Figure 13 illustrates the wide range of costs and capacities provided by different types of public transport investments.

Figure 13: Typical Capital Costs vs. Passenger Capacity for Urban Transport



BRT = bus rapid transit, km = kilometer, LRT = light rail transit.
Source: L. Wright and W. Hook. 2007. *Bus Rapid Transit Planning Guide*. Institute for Transportation and Development Policy. New York. http://www.itdp.org/index.php/microsite/brt_planning_guide/

107. **Character and disposition of public transport and private vehicles can have significant impacts on CO_2 and the cost-effectiveness of mobility provision.** The degree to which new high capacity public transport services displace rather than augment existing motor vehicle use (whether public or private vehicles) makes a significant difference in the CO_2

reductions produced by public transport investment. For maximum CO_2 benefits, it is desirable for new public transport services to shift travel from less efficient modes and vehicles to more efficient vehicles and modes of travel. This may be maximized when the new public transport investment involves scrapping old, inefficient vehicles (rather than merely exporting them for reuse elsewhere) or reducing their continued use through measures such as road space reallocation or road pricing. The costs of such measures need to be factored into CO_2 mitigation costs. For example, while compressed natural gas buses produce 10%–15% less GHG emissions than conventional diesel buses, they entail vehicle costs that can be about 20% higher. In addition, their specialized refueling stations can cost $1.5–$2.5 million each, and may create fuel sourcing problems. These factors make it important to consider fiscally constrained trade-offs between various strategies if the goal is to maximize mobility per unit of CO_2 within limited capital and operating budgets.

108. **Cost-effectiveness of public transport carbon dioxide reduction depends on fuel source and system efficiency.** MRT systems are usually electric traction, giving them a potential CO_2 operating advantage over BRT. This may be diminished if the power for the MRT is derived from coal or other CO_2 intensive power sources. Vehicle occupancy is also a key factor. If an MRT or BRT system operates with low vehicle occupancy for much of the day, it will be far less efficient in both cost recovery and CO_2 emissions per passenger-km than if it is designed and operated for higher vehicle occupancy. While overloaded conditions are highly CO_2 efficient on per passenger-km carried basis, they are likely to drive away choice riders to other modes of transport that may be more CO_2 intensive. Thus, a balance should be struck to produce optimal cost and CO_2 efficiency.

109. **Sound financing systems for metro rail transit or high-capacity bus rapid transit can boost carbon dioxide reductions.** MRT requires less surface right-of-way and offers moderate to high-speed mobility for very high passenger volumes. Thus, it can support the highest density urban development that is often associated with the lowest overall GHG footprint measured in terms of CO_2 intensity per person per job or per household. MRT is often justified by its role in shaping long-term urban development, although high-capacity BRT can provide similar benefits. Building an MRT system or high-capacity BRT in most circumstances will create a substantial increase in land values for properties in close proximity to stations. If such properties are regulated by the government through zoning, some or most of this increase in value can be captured by ensuring these land parcels are developed at suitably high densities, generating a sustainable stream of land rents or taxes that can be used to pay for the cost of developing and subsidizing the operation of MRT or high capacity BRT.

IV. IMPLICATIONS FOR ADB

110. The above findings have generated several implications for ADB, ranging from quality-at-entry to monitoring and benchmarking. These are summarized below.

A. Raising Awareness of Carbon Emissions

111. **ADB needs to consider raising awareness of carbon emissions among its member countries, stakeholders, and staff.** This EKB explores the implications of ADB's transportation activities with respect to climate change in a new manner that has not been previously undertaken. It suggests ways that ADB might adjust its transport investment activities to reduce carbon emissions while fulfilling its mission to support equitable economic and social development. It is important for ADB to raise wider awareness among decision makers and stakeholders in DMCs about the potential for win-win strategies that fulfill both the environment and development goals. Efforts are also needed to help ADB transport staff and consultants to

understand these opportunities and relationships. To be successful in shifting ADB's portfolio and project designs in ways that fully exploit the potential for low-cost sustainable transport will require consciousness of carbon emission reduction goals in the development of country strategies and the earliest development and consideration of investment alternatives in the transport sector and related initiatives that focus on economic, housing, and community development.

B. Dynamic Baselines are an Important Framework for Considering Emission Reductions

112. **ADB needs to consider making use of dynamic baselines to consider carbon dioxide emission impacts of projects, comparing projects against business-as-usual scenarios.** This EKB analysis highlights that dynamic baselines are useful for carbon analysis. Although some have argued that "energy saving from a modal shift is constant over time,"[73] this assertion is based on an assumption that there is a constant mode share in a city or corridor over the time frame of analysis. Across most of the rapidly developing cities of Asia, the recent trend is falling mode shares for public transport, walking, and cycling in the face of rapidly increasing motorization.[74] This has led to wider acceptance of dynamic baselines to evaluate transportation GHG emissions in several situations. Rather than assuming a fixed backdrop for implementation over time in the business-as-usual case, the analysis compares an action scenario vs. a business-as-usual case in which recent trends of modal change and traffic growth continue unabated. Such an approach is most relevant to public policy analysis, sectoral CO_2 analysis and reporting, development of nationally appropriate mitigation actions (NAMAs), and evaluation for some carbon finance incentive programs such as GEF.

113. **ADB needs to consider monitoring of absolute carbon dioxide emissions at project level.** ADB's Safeguards Policy Statement highlights the need for the borrower or client, i.e., the DMCs to monitor projects that emit higher than 100,000 tons of carbon dioxide per year. Dynamic baselines derived from recent trends should not be taken as the ultimate goal but need to be used as reference frameworks that can be modified by changes in policies, investments, planning frameworks, and pricing. Sensitivity analysis is warranted where there is significant uncertainty about projection of transportation and development trends. The various ways that transport CO_2 project appraisals can inform the development of regional low carbon growth plans need to be considered. In this context, both dynamic baselines and absolute emissions matter.

C. Improving ADB's Economic Analyses

114. **ADB needs to consider including the impacts of savings in CO_2 and air pollution emissions on economic viability.** Economic analysis of transport projects is one of the factors used in investment decision making. In the past, ADB and its DMCs have not used emissions generated by projects in quantifying costs and benefits, citing lack of an accurate methodology and data for computing emissions. The TEEMPs provide a reasonable methodology for

[73] O. Grandvoinet and C. Bernadac. 2009. *Carbon Footprint Methodologies for Development Projects and Case Studies*. Agence Française de Développement. http://www.dev-practitioners.eu/fileadmin/Redaktion/GroupsFolders/Climate_Change/Workshop_09-03/AfD_Workshop_Carbon_footprint_-_March09.ppt

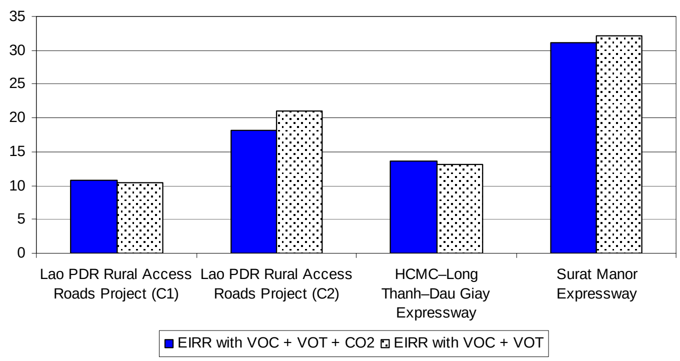
[74] IPCC, Working Group III: Mitigation of Climate Change. 5.3.1.5 Road Transport: Mode Shifts. *IPPC 4th Assessment Report, Climate Change 2007*. http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch5s5-3-1-5.html

estimating project emissions, which can in turn be used to help assess the economic internal rate of return (EIRR), rather than considering CO_2 emission reduction solely as a co-benefit.[75]

115. Toward this end, three transport projects[76] were evaluated with the TEEMP and compared with the business-as-usual scenario to estimate the net impact of CO_2 emissions on the calculated EIRR. Using international good practices,[77] the emissions were converted into monetary terms—with CO_2 considered at $85 per ton, particulate matter (PM10) considered at $15,000 per ton, and NO_x considered at $3,500 per ton.[78]

116. An important finding of this EKB analysis is that for projects having high EIRR, the impact of CO_2 on economic analysis is found to be marginal and may not influence decision making. However, for projects that have an EIRR around 11%–13%, i.e., those that are marginally feasible or unfeasible, the impact of CO_2, particulate matter, and NO_x could be decisive. Figure 14 shows that the EIRR shifts most notably for the Lao People's Democratic Republic rural access roads and the expressway project in Viet Nam.

Figure 14: Impact of Carbon Dioxide Emissions on Economic Internal Rate of Return (%)



CO_2 = carbon dioxide, EIRR = economic internal rate of return, HCMC = Ho Chi Minh City, Lao PDR = Lao People's Democratic Republic, VOC = vehicle operating cost, VOT = vehicle operating time.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports.

117. Another important finding was that NMT projects like Marikina bikeways,[79] which have low investment costs, can prove to be economically feasible with the quantification of just air pollutants and CO_2 emissions. IED analysis shows that the EIRR based on benefits from air

[75] L. Schipper. 2009. Presentation on Saving CO_2 in Transport and Living to Measure the Savings. Meeting on Scientific Technical Advisory Panel. http://www.adb.org/Documents/Events/2009/Scientific-Technical-Advisory-Panel/schipper-unep.pdf (accessed 27 May 2010); S. Gota and H. Fabian. 2009. Presentation on Estimating Emissions from Land Transport at Country, City and Project Levels – a Critical Look at Theory and Practice. Meeting on Scientific Technical Advisory Panel. Manila. http://www.adb.org/Documents/Events/2009/Scientific-Technical-Advisory-Panel/Gota-Fabian.pdf (accessed 27 May 2010).
[76] The three ADB projects are (i) Ho Chi Minh City–Long Thanh–Dau Giay Expressway, Viet Nam; (ii) Surat–Manor section of National Highway 8 expressway, National Highways Development Project in India; and (iii) the Lao People's Democratic Republic Rural Access Roads Project (C1 and C2).
[77] Various sources – HM Treasury. 2006. *Stern Review on the Economics of Climate Change*. London; A.K. Sen, G. Tiwari and V. Upadhyay. 2010. Estimating Marginal External Costs of Transport in Delhi. Transport Policy via Elsevier Science Direct, Vol. 17, Issue 1; January 2010; pp. 27–37; Victoria Transport Policy Institute. Transport Demand Management Encyclopedia on Transportation Costs and Benefits. http://www.vtpi.org/tdm/tdm66.htm#_Toc18284952 (accessed 27 May 2010); Transport Canada. 2008. *Estimates of the Full Cost of Transportation in Canada*. Ottawa.
[78] The health and social impacts of air pollution depend on several issues including type of pollutant, concentration, other pollutants, length of exposure, etc. These impacts need to be estimated based on epidemiological studies.
[79] This project was not funded by ADB.

pollutants and CO_2 emissions only (excluding fuel savings) is about 12%. This creates an important factor for justifying the project.

118. A preliminary finding that merits more investigation is that projects such as expressways that increase emissions also result in higher fuel use, which is a significant component of VOCs. For example, the Surat–Manor expressway shows a very high rate of return of 32%, and high savings in VOCs, with cumulative savings of $4,734 million over 20 years. However, the project shows an increase in emissions when compared with the business-as-usual scenario, with a net economic cost of $1,220 million. This increase in emissions indicates an increase in fuel consumption, which is a dominant component of VOCs.[80] This aspect needs more investigation, with appropriate consideration of induced traffic in travel forecasting as part of feasibility analysis. The underlying implication here is that an increase in traffic does not always yield higher benefits.

D. Carbon Intensity Monitoring

119. **ADB could consider monitoring the intensity of CO_2 emissions related to its projects.** As ADB significantly increases its lending in the transport sector, it may consider reducing CO_2 emissions per km, per passenger-km, per ton-km, and/or per USA dollar of capital investment over time, as appropriate, in both gross terms and in terms of net impact on transport sector CO_2 emissions with respect to a business-as-usual case. In achieving this, ADB will be able to demonstrate leadership as a development institution and as a steward of the environment and natural and capital resources. This EKB demonstrates that ADB has the tools to measure its performance in these respects. ADB needs to ensure that these tools are employed as part of an overall institutional management strategy.

E. Strategy for Carbon Emissions Mitigation

120. **ADB could adopt a short-term and a long-term strategy for addressing carbon emissions.** This includes adopting goals for reducing the carbon intensity of its investments in several dimensions. ADB's investment strategies could consider a shift in modal emphasis away from promoting unmanaged motorization. ADB needs to give greater priority to integrated transport and land use strategies that support NAMAs for sustainable low carbon transportation. These link to urban and rural public transport, NMT and traffic safety, travel demand and traffic management, and intermodal freight and logistics systems development. ADB needs to consider how to integrate carbon emissions mitigation into transport project and country plan development at the earliest possible stages, before projects are specified and put into the lending pipeline. In addition, ADB needs to explore how to reduce the carbon footprint of projects in the pipeline for assistance by adding low carbon sustainable transport elements and rethinking high-carbon elements. This is expected to contribute to the Strategy 2020 by aligning with its environmental goals as well as with the broader equitable economic development objectives and cost-effectiveness.

F. Urban Planning and Management rather than Transport Plans and Capital Projects

121. **ADB needs to consider support for integrated approaches to urban planning and management.** A key to start is for ADB to focus a portion of its resources in support of sound urban planning and operations management that integrates transportation, urban design, land use, and natural resource protection concerns. ADB needs to focus more resources on helping

[80] VOCs include fuel, oil, tires, parts consumption, vehicle utilization, and depreciation. It can be argued that fuel alone contributes more than 60% of VOCs. The project increases fuel consumption by more than 5,500 million liters of gasoline and diesel combined.

metropolitan areas and DMCs consider how such integrated planning and operations management can support NAMAs and related low carbon growth plans. This will require institutional capacity building and training both within DMCs and within ADB, as well as funding of pilot programs in key cities that demonstrate good practices. It will require new professional partnerships to integrate architecture and urban design professionals, social scientists, and planners with civil engineers, economists, and more traditional transport decision makers and experts. ADB needs to focus on helping interested member governments demonstrate short-term progress in reducing CO_2 intensity through smart integrated management strategies. Too much emphasis on long-term planning exercises could distract attention from the need to show near-term capacity for institutional learning and adaptation.

122. **ADB needs to consider how to include public transport in transport projects.** Construction or improvement of low volume rural roads is often vital to the provision of public transport or privately provided intermediate transport services in rural areas. These services will produce some increase in GHGs. However, at low volumes, these are small relative to the benefits in terms of improved access to health care, education, markets, and services for otherwise isolated and often poor rural communities. Providing access to such services is likely to raise rural incomes and facilitate rural development. It could also improve sustainability of rural economy. In urban projects, ADB needs to include a public transport component in its urban initiatives where feasible.

V. RECOMMENDATIONS

A. Adopt Carbon Emissions as a Consideration for Project Design, Review, and Appraisal

123. **Pilot test carbon emission reduction strategies in transport project designs.** ADB's Safeguards Policy Statement requires quantification and monitoring of carbon emissions by the borrower/client (para. 14). Strategy 2020 emphasizes reduction of carbon footprint and moving to lower CO_2 emissions. While economic development will continue to be the prime driver for transport projects, ADB needs to encourage the use of physical designs that enable a smaller carbon footprint, considering cumulative construction, maintenance, and operations emissions, including induced impacts. Other multilateral development agencies such as the GEF and the World Bank are in the process of developing similar methodologies for carbon footprinting. ADB needs to work in conjunction with such agencies to develop a compatible mechanism for estimating CO_2 emissions. Once such a mechanism is developed, it needs to be pilot tested selectively starting with new projects. Based on the outcome, ADB could consider mainstreaming the use of carbon emissions as a consideration in transport project design, review, and appraisal for projects with significant carbon emissions. Such mainstreaming will have resource implications within ADB as well as in the DMCs. ADB will need to be cognizant of the capacity within the DMCs to collect data and ensure adequate monitoring of these emissions. Countries with relatively weak capacities such as in the Pacific will need appropriate assistance before mainstreaming.

124. For road construction, the most appropriate methods and materials depend on local soil and drainage conditions, topography, expected traffic loads, climactic conditions, and other factors. Life cycle analysis methods could be more widely used to integrate consideration of CO_2 minimization goals into transportation facility construction, design, and maintenance, considering appropriate trade-offs with regard to vehicle operations emissions, which dominate the overall carbon footprint of most infrastructure. Nonetheless, construction or expansion of new high-speed highways in both rural and urban areas can produce significant carbon

emissions. ADB's project preparatory activities need to identify construction options for technology and materials that will serve to minimize emissions during construction to the extent feasible in a cost-effective manner.

125. Since 2009, one of the ADB-funded projects had considered carbon emissions in project approval and another one is in the process of adopting a similar consideration. The Lanzhou Sustainable Transport Urban Transport Project in the PRC quantified carbon emissions benefits during its economic appraisal. The Ho Chi Minh City Metro Project in Viet Nam is currently in the process of using such tools for estimating carbon emissions for an MRT system to be funded by ADB. Similarly, ADB could identify various mechanisms to pilot and subsequently mainstream the use of carbon emissions in future projects. Suggestions for such mechanisms are summarized below.

126. **Consider use of emission models for transport project appraisal covering both carbon dioxide and air pollutants.** ADB needs to consider including CO_2 and other air pollutants in estimating project economic viability as these can be decisive in some cases, and reasonable and efficient methods exist to quantify these elements in calculating EIRRs for projects. After adopting these assessment tools, ADB could expand their usage by supporting local and global capacity building to improve these analysis tools for transportation planning and evaluation, together with better transportation network analysis and travel behavior analysis tools. The TEEMP suggested by this EKB can be a starting point for mainstreaming the measurement and monitoring of these emissions.

127. **Consider inclusion of alternative analysis in proposals for highways, expressways, and metro rail transit projects.** ADB needs to encourage proposals for new or expanded highways aimed at serving improved logistics in a corridor to consider whether investment in new or improved railway, waterway, or intermodal freight systems might provide effective complementary or alternative capacity to address the same needs with a smaller carbon footprint. This will need to be implemented on a case-by-case basis, i.e., an alternative analysis needs to be carried out where alternatives to highways are possible. Where feasible, proposals for highways aimed at serving improved passenger movement in a corridor need to be subjected to alternative analysis that considers whether investment in new or improved public transport services, including better bus or rail services, might provide effective complementary or alternative capacity to address the same needs with a smaller carbon footprint.

128. **Promote sound baseline data collection and development of carbon emissions monitoring tool.** ADB needs to build on its recent initiatives to develop a knowledge base for evaluating the CO_2 impacts of transportation by requiring sound baseline data collection in all new ADB transportation projects. This could follow the recommendations of the ADB report, *Transport and Carbon Dioxide Emissions: Forecasts, Options Analysis, and Evaluation*.[81] In addition, project analysis at appraisal stage need to apply dynamic baseline scenarios in CO_2 impact analysis linked to changes in policies, investments, planning frameworks, and pricing. ADB currently lacks a systematic framework for collecting data needed to establish more rigorous baseline CO_2 emissions, considering CO_2 emissions in project appraisal, and monitoring CO_2 emissions intensity throughout the life of projects it finances or assists. Improved data are needed on vehicle activity, network travel speeds, mode shares, public transport ridership, trip lengths by mode, and other parameters that influence CO_2 baseline emissions and project impacts. Environmentally sensitive project analysis, evaluation, and

[81] L. Schipper, H. Fabian, and J. Leather. 2009. ADB Sustainable Development Working Paper Series No. 9. *Transport and Carbon Dioxide Emissions: Forecasts, Options Analysis, and Evaluation.* Manila: ADB.

planning could seek to analyze current conditions, understand recent trends, and take account of planned or reasonably anticipated demographic, spatial, economic, technology, and mobility policies. This is an area that merits early action by ADB.

129. **Further refine carbon footprint analysis tools in conjunction with other agencies.** ADB could further refine carbon footprint impact analysis tools for project, city-level plan, and program analysis, in cooperation with other regional development banks, the World Bank, and other stakeholders, such as the GEF and the Partnership on Sustainable Low Carbon Transport. This EKB has estimated a preliminary carbon footprint for ADB's transport projects approved from 2000 to 2009 using coefficients derived from a small sample of representative projects, classifying the full portfolio list by project type, and using appropriate weighting factors. This analysis needs to be further refined by examining additional cases, refining the emissions factor models by project type and improving the sample of projects. This would require additional work to estimate relative demand weights for different project types. Better data is needed on construction emissions for ADB railway projects and to distinguish between at-grade, elevated, and underground sections of highway and MRT projects and between heavy and light rail. It would be helpful to develop a carbon footprint analysis model that can quickly assess differences between different types of geological conditions and various tunneling vs. cut-and-cover construction methods. For this, additional data collection is needed.

B. Encourage Modal Shift in ADB Investments

130. Economic development is expected to remain a major driver for decisions on prioritizing and designing transport projects. ADB's Sustainable Transport Initiative Operational Plan has identified medium to long term climate change mitigation strategies. The main strategy of this plan is to shift ADB's expanding operations toward lower carbon emissions and energy consumption modes, e.g., it states that railways and inland waterways offer more efficient and lower emission transport solutions for long distance and passenger traffic. Taking this initiative forward, this EKB encourages inclusion of a new factor in the appraisal process. Consideration of carbon emissions could enable a gradual shift in the modes of transport that ADB will invest in the future. This shift is expected to be a long-term process and will not replace the existing drivers of decision making for transport projects, i.e., improvements in access and mobility. Given below are various options for enabling this change.

131. **Consider nonmotorized transport improvements in its transport portfolio.** With the envisaged growth in urban transport projects, ADB has the opportunity to take on board the findings of this EKB in relation to the NMT solutions. Other measures, such as improving traffic management and encouraging better public transport systems, could be adopted. To limit its carbon footprint, ADB could initiate efforts directed toward expanding its investment portfolio to include bicycle and pedestrian improvements as a standard part of all road and public transportation projects in or near cities and towns. This will require a broader urban planning perspective. Such low-cost modes of transport tend to be marginalized and disadvantaged by large-scale transportation investments unless made an explicit part of the project planning and development. Such urban road improvements could also benefit from the use of global good practice street design standards, such as those from the United Kingdom, Germany, and Abu Dhabi.[82] Suburban roads could be designed with good practice standards such as those recently reformed in the USA.[83]

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[82] Abu Dhabi Urban Planning Council. 2010. *Abu Dhabi Urban Street Design Manual, Version 1.0*. Emirate of Abu Dhabi. http://www.upc.gov.ae/Libraries/Forms_Ar/Street_Design_Manual_English_small_FINAL.sflb.ashx

[83] Institute for Transportation Engineers. 2008. *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach – Second Draft.* Washington, DC.

132. **Engage with developing member country governments to encourage low carbon projects.** Typically, ADB's country programs are identified in line with the DMCs' development plans. This gives limited room to maneuver for ADB to incorporate carbon emissions friendly modes of transport into its programs unless there is adequate ownership within the DMC for such changes. Within this limitation, ADB could engage in a policy dialogue with the DMC governments to fine-tune its program for including low carbon intensity projects.

133. **Make sustainable low carbon transport a management priority.** Sustainable economic development is likely to remain a key driver for ADB's projects in the transport sector. Taking into account the range of transport modes, ADB could enable a shift in its funding from less sustainable transport projects, such as exclusive road widening, to more innovative low carbon strategies that better support sustainable development. Exceptions could be made for rural roads and highways, which are designed for improving access to remote areas. ADB could set a goal of becoming much more climate-positive in its transport lending by supporting low carbon growth plans. These concepts could be incorporated into the country programming missions, which could conduct policy dialogue targeted at rational energy and transport pricing, appropriate transport modal mix, transfer of energy efficient technologies and integrated urban planning.

C. Consider Systematic Intensity Indicators in Alignment with Strategy 2020

134. ADB's Strategy 2020 states that it will help the DMCs to move their economies onto low carbon growth paths by modernizing public transport systems. This is an important goal that needs action and monitoring. Timely progress in CO_2 reduction will be compromised unless staff and management at all levels perceive this to be a core part of ADB's organizational strategy. ADB needs to consider establishing the carbon footprint of its transport sector assistance, taking into account the fact that this is its largest sector in terms of lending volume. The link with Strategy 2020 will require benchmarking of the carbon footprint against the low carbon growth path. This will provide ADB with the knowledge of the "carbon effectiveness" of different projects. It would also allow developing countries to learn from such an initiative. With limited funding available, there is a need to prioritize the options to provide best solutions, considering the externalities relating to the impact on climate change.

135. This EKB has introduced the following CO_2 intensity reduction indicators for transport projects:

- (i) outputs in terms of CO_2 intensity per km of infrastructure constructed,
- (ii) mobility in terms of CO_2 intensity per ton-km (freight) and per passenger-km, and
- (iii) investments in terms of CO_2 intensity per $1 million spent on transport projects.

136. Based on the Sustainable Transport Initiative Operational Plan, ADB could consider targets for improving one or more of the above intensity indicators, based on the project priorities and data available. These targets can set the direction without specifying how the targets are to be achieved. This gives flexibility to loan/project developers at ADB to decide on what measures to use to achieve the target. The target for the project level could be set low initially and strengthened as ADB's climate change accountability initiatives develop. The weights given to the individual targets will depend on the project context.

D. In Partnership with the DMC Governments, align ADB's Sustainable Transport Initiatives with Nationally Appropriate Mitigation Actions

137. ADB needs to coordinate transport sector assistance with DMCs' NAMAs. Asian countries are in the process of developing their policies and voluntary actions to reduce GHG emissions.[84] As and when these changes have been finalized, ADB needs to coordinate its evolving climate change initiative to the action plans of its DMCs. The NAMAs are being developed under the framework of the global climate negotiations, and the related low carbon growth plans. Several countries in the region have identified transportation as an area where they seek to achieve CO_2 emission reductions. ADB needs to support these initiatives with targeted technical assistance, capacity building, and lending. This presents a strategic opportunity for ADB to partner with climate change leaders at the national and municipal levels in the transport sector.

[84] United Nations Framework Convention on Climate Change. 2009. *Handbook*. Bonn, Climate Change Secretariat.

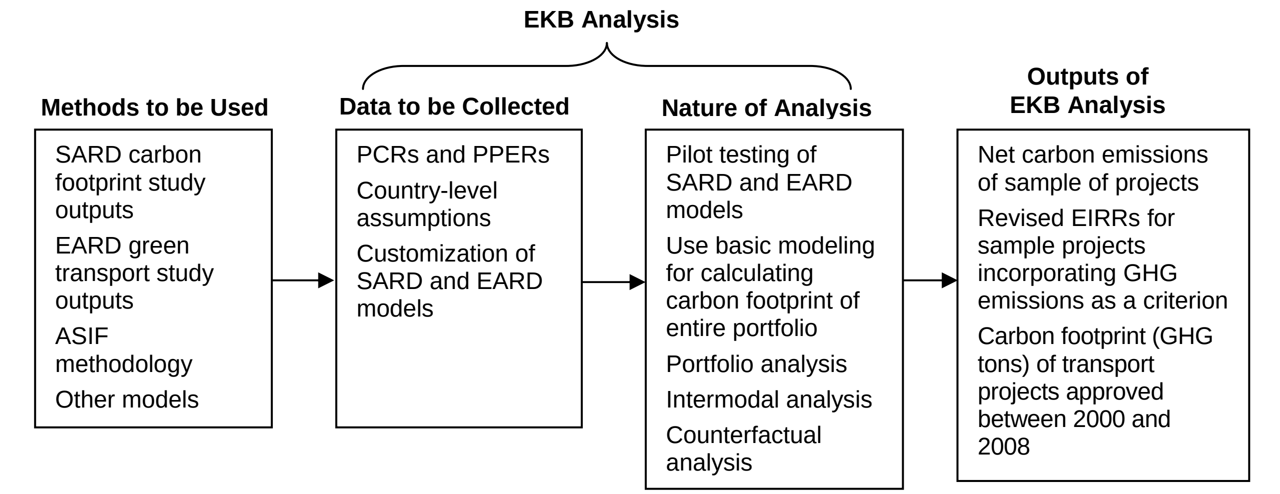
OVERVIEW OF PROJECTS EVALUATED IN-DEPTH FOR CARBON DIOXIDE IMPACT

Project Type	Project	Funding Source
City Analysis	Passenger road transport system of Metro Manila, Philippines (i.e., motorized, public, and nonmotorized transport combined)	Other (MMUTIS)
Expressways	Salem–Namakkal stretch of NH-7, NHDP projects in India	Other (NHDP)
	Ho Chi Minh City–Long Thanh–Dau Giay Expressway, Viet Nam	ADB
	Surat–Manor section of NH-8, NHDP projects in India	ADB
	Belgaum–Dharwad section of NHDP, India	Other (NHDP)
Metro Rail Transit	Ho Chi Minh City Metro Rail System Project, Viet Nam	ADB
	Manila LRT-1 North Extension, Philippines	Other (DOTC)
	Bangalore Metro, India	Other (BMRC)
Bus Rapid Transit	Hypothetical cases of Manila LRT-1 North Extension, Philippines, and Bangalore Metro, India	Other (Government)
	Lanzhou Sustainable Urban Transport Project	ADB
Nonmotorized Transport	Marikina Bikeways, Philippines	GEF
Railways	Hefei–Xi'an Railway Project, PRC	ADB
Rural Roads	Kazakhstan and the Kyrgyz Republic: Almaty–Bishkek Regional Road Rehabilitation Project	ADB
	Lao PDR Rural Access Roads Project	ADB

ADB = Asian Development Bank, BMRC = Bangalore Metro Rail Corporation, PRC = People's Republic of China, DOTC = Department of Transportation and Communication, GEF = Global Environment Facility, Lao PDR = Lao People's Democratic Republic, LRT = light rail transit, MMUTIS = Metro Manila Urban Transportation Integration Study, NH = national highway, NHDP = National Highways Development Project.
Source: Independent Evaluation Department.

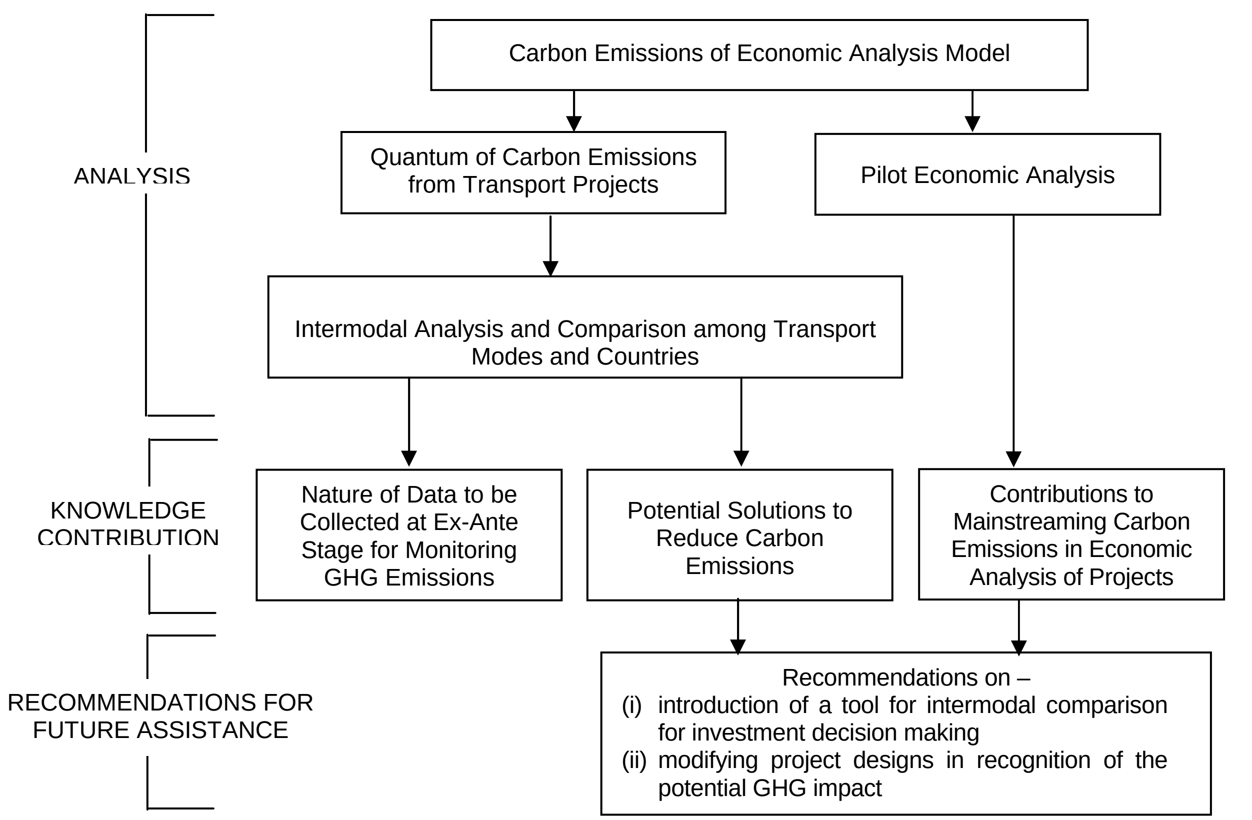
METHODOLOGY FOR THE EVALUATION KNOWLEDGE BRIEF

Figure A2.1: Evaluation of the Impact of ADB Assistance



ADB = Asian Development Bank, ASIF = activity–structure–intensity–fuel, EARD = East Asia Department, EIRR = economic internal rate of return, EKB = evaluation knowledge brief, GHG = greenhouse gas, PCR = project completion report, PPER = project performance evaluation report, SARD = South Asia Department.
Source: Independent Evaluation Department.

Figure A2.2: Output of the Evaluation Knowledge Brief



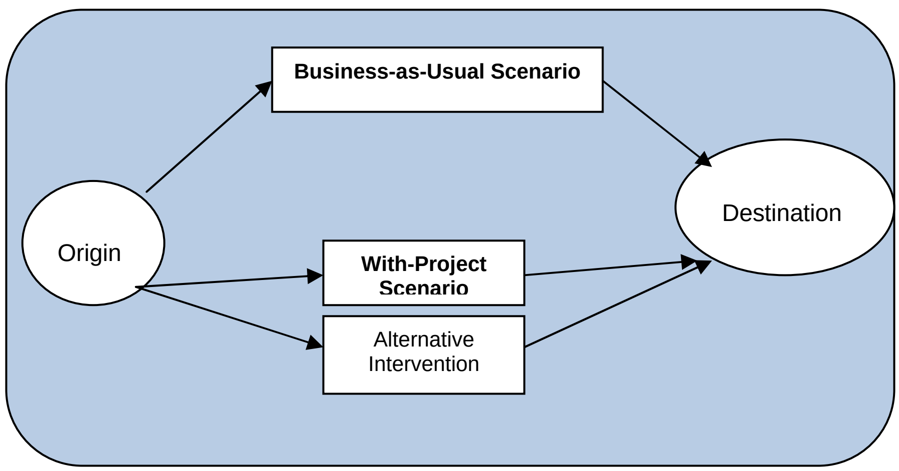
GHG = greenhouse gas.
Source: Independent Evaluation Department.

METHODOLOGY FOR TRANSPORT EMISSIONS EVALUATION MODEL FOR PROJECTS

A. Background

1. The methodology for various transport interventions is generally founded on the activity–structure–intensity–fuel (ASIF)[1] philosophy, which connects activity (passenger and freight travel) with structure (shares by mode and vehicle type), with intensity (fuel efficiency), and with fuel type. Modes considered are land-based and the interventions mapped include high-speed highways, rural access supportive roads, urban roads, public transport projects such as metro rail transit (MRT) and bus rapid transit (BRT) systems, and railways and bikeways. The methodology compares the business-as-usual scenario with various intervention options (Figure A3.1).

Figure A3.1: Basic Structure of Transport Emissions Evaluation Model for Projects



Source: Independent Evaluation Department.

2. The model evaluates the impacts of transport projects on carbon dioxide (CO_2) emissions and to some extent air pollutant emissions using data gathered during project feasibility and actual operations. The models have been derived based on the existing quantity and quality of data gathered to evaluate their economic feasibility and minor suggested additions to encompass the emissions quantification which would give some rapid assessment, reasonable direction, and allow alternative options evaluation.

3. Spreadsheet models have been developed for (i) rural roads improvement, (ii) urban roads improvement, (iii) bikeway improvement projects, (iv) rural expressways, (v) light rail transit (LRT)/MRT projects, (vi) BRT system projects, and (vii) railway projects. These models can be downloaded using the following internet link – http://www.adb.org/evaluation/reports/ekb-carbon-emissions-transport.asp.

4. The methodology encompasses both with- and without-project cases, and emissions saved are quantified with the assumption that no major improvement would have happened in the scenario without the project. The emission quantification methodology ASIF is described in Table A3.1.

[1] L. Schipper, M.L. Celine, and R. Gorham. 2000. *Flexing the Link between Transport and Greenhouse Gases: A Path for the World Bank*. Paris: International Energy Agency (June).

Table A3.1: Activity–Structure–Intensity–Fuel Summary

Driving Forces	How Many Trips	How Many km Traveled	How are km Traveled?	Routes	Vehicle-km by Fuel and Other Vehicle Characteristics	Fuel Use and CO_2 Emissions
Land uses, population, demographics, incomes, and gross domestic product	Activities that join origins and destinations, providing data on trips. For example, employment generates a trip from home to work in the morning and back in the evening. A stop for food shopping might be made on the way	Separation of origins and destinations, but distance subject to actual route taken	Mode choices	Route, network conditions, speeds that give actual distances traveled, and actual distances vehicles move	Changes in vehicle activity and speeds over routes by vehicle type and fuel	Changes in km traveled by vehicle type, and changes in fuel use/km by vehicle type, for each fuel
Driving forces	Incomes, lifestyles, socio-demographic status	Profoundly affected by density and land uses, availability of modes, speeds	Choices affected by land uses, incomes, locations of “origin” and “destination,” incomes, relative speeds and travel times, safety, and overall service	Relates to traditional traffic engineering and transport planning	Costs of a vehicle-km (fuel, tolls, parking); traffic conditions, i.e., speed and congestion	Engine technology, driving style
Best data sources	Origin–destination surveys and commodity flow surveys for freight	Same as previous	Same as previous, but also data from passenger and freight operators, on board surveys of travelers	Visual observations, traffic counts, speed measurements	Surveys of individual vehicle use; data from fleet operators (taxi, bus, truck)	Fuel use can be measured from surveys, estimated according to simulation models adjusted to local traffic conditions, or imputed from fuel sales, vehicles, and vehicle kilometers
Where in ASIF?	Combined, these data give passenger-km (or ton-km) by mode.				Do not appear directly in ASIF	Fuel use appears as numerator in “I”; fuel use multiplies carbon coefficient “F” gives the CO_2 emissions intensity by mode.

ASIF = activity–structure–intensity–fuel, CO_2 = carbon dioxide, km = kilometer.

Source: Adapted from L. Schipper, H. Fabian, and J. Leather. 2009. Asian Development Bank (ADB) Sustainable Development Working Paper Series No. 9. *Transport and Carbon Dioxide Emissions: Forecasts, Options Analysis, and Evaluation.* Manila: ADB.

5. The models developed for project evaluation borrow heavily from detailed methodologies such as the Computer Programme to Calculate Emissions from Road Transport (COPERT)[2] and allow users to put in default emission factors primarily to capture the impact of speed. The impact of age (age deterioration factors), grade, and temperature are not considered in the developed methodology/model to reduce the assumptions. Since the motive of the methodology is to compare project alternatives using the majority of data collected at the feasibility stage, there is a need to link emissions methodology with the data collated to capture fuel savings, which is a primary benefit/cost of the project (road user cost). The fuel split currently captures gasoline and diesel fuel only.

B. Determining and Using Baselines: Static vs. Dynamic

6. This EKB uses the three terms to convey the same meaning—dynamic baseline, business-as-usual scenario, and no-project scenario. To evaluate the CO_2 emission impacts of transportation projects and programs requires establishing a baseline for measuring the savings in emissions. There are several ways to define a baseline. Analysis using a *static baseline* would compare conditions at some fixed time either current or past to what would happen if a given project or program of projects were to be implemented. Analysis using a *dynamic baseline* would compare projected conditions at future points in time under a business-as-usual case with what would happen if a given project or program of projects were to be implemented.

7. Each approach to baseline measurement has its value. A static baseline is useful for considering whether absolute emissions are likely to rise or fall and by how much, compared with today or to a time in the recent past. The overwhelming consensus of the global scientific community, as expressed through the Intergovernmental Panel on Climate Change, is that global emissions of greenhouse gases need to be reduced by half from 1990 levels by 2050. Various authorities have adopted complementary greenhouse reduction goals for different time horizons, e.g., calling for a 20% reduction in greenhouse gases by 2020 from a 2006 baseline. Determining the relative or proportionate contribution of transportation toward such goals requires use of a static baseline to evaluate change in emissions, using 1990, 2006, or another year as a baseline. It is usually easier to gain concurrence about static baseline definitions, since they can be based on recent observations and data estimates. But a static baseline evaluation will mask the discrete effect of a specific project or investment program, which will be lost in the larger set of changes in vehicle technologies, fuels and land use, economic, and transport activity patterns.

8. A dynamic baseline is useful for recognizing the contribution of projects or programs for reducing emissions from the most likely current trend or business-as-usual forecast of emissions. In most developing countries, trends favor rapid growth in motor vehicle ownership and use, changes in public transport, walking, and cycling mode shares, and shifts in the character of the motor vehicle fleet away from use of 2-stroke engines, with changes in the share of trips by motorized 2-wheelers, and sometimes changes in the attributes of motor fuels. These trends will be explicitly accounted for in a dynamic baseline evaluation. Thus with a dynamic baseline, it becomes easier to discern the discrete contribution to increasing or reducing emissions of a project or investment program.

[2] COPERT is a Microsoft Windows software tool for the estimation of GHG emissions from road transport. The emissions cover the major pollutants viz. carbon monoxide, nitrogen oxide (NO_x), particulate matter, and sulphur dioxide; as well as GHGs including CO_2. COPERT has been developed by the European Topic Centre on Air and Climate Change and is supported by the European Environment Agency. The COPERT 4 methodology has been included in a guidebook developed by the United Nations Economic Commission for Europe Task Force on Emissions Inventories and Projections.

9. The TEEMP employs a dynamic baseline approach. The input assumptions used for each mode in the TEEMP dynamic baseline evaluation are detailed in the subsequent sections of Appendix 3. Dynamic baselines include trends in motor vehicle ownership and use, changes in public transport patterns, transport mode shares, composition of the motor vehicle fleet, and sometimes changes in the attributes of motor fuels. These changes are largely characterized by changes in traffic and vehicle speeds, which have been captured by the TEEMPs. In contrast, static baselines compare conditions at some fixed time either current or past, assuming constant parameters of traffic, vehicle speed, vehicle ownership levels, and transport and trip mode share.

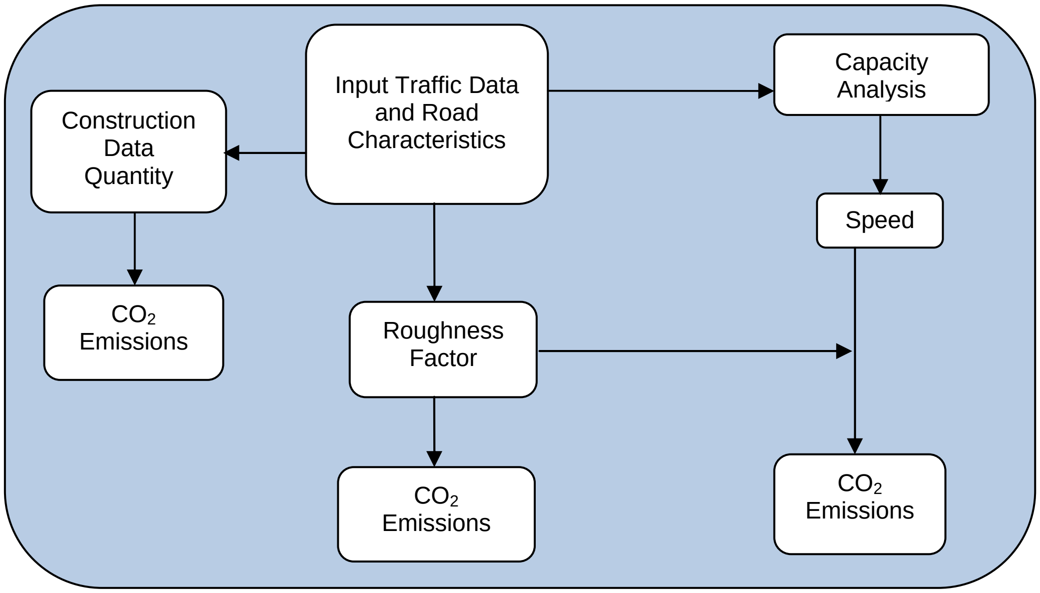
10. Users of the TEEMP need to consider how changes in various macroeconomic factors and policies may affect the dynamic baseline. For example, if it is anticipated that, in the near future, a country might phase-out large motor fuel subsidies and adopt more stringent motor vehicle fuel economy standards or high motor vehicle registration fees on less efficient vehicles, which might be undertaken as unilateral nationally appropriate mitigation actions (NAMAs) to cut CO_2 and enhance energy security, these are likely to influence the character of the motor vehicle fleet and the intensity of motor vehicle use. In the context of evaluating potential supported NAMAs, such as a new BRT or nonmotorized transport (NMT) system in a city, inputs to the TEEMP could be adjusted to separately evaluate the likely effects with or without the unilateral NAMAs. This could provide two dynamic baselines for project evaluation—one under business-as-usual and one in the context of the unilateral NAMAs. It is also possible to produce multiple dynamic baselines for a project or program, with scenarios that vary by their assumptions of gross domestic product or population growth rates.

11. Because dynamic baselines are sensitive to variations in multiple basic assumptions, they should be used with care, transparency, and efforts to explicate key assumptions. They need to be updated periodically with more current assumptions and measured data. A sharp economic downturn or boom, sharply higher or lower oil prices, or major civil conflict or natural disaster can wreak havoc with the best of assumptions, rendering prior dynamic baselines obsolete. Nonetheless, it is valuable to be able to anticipate where trends are headed and to evaluate how particular interventions might produce more desirable outcomes or system performance. Indeed, under the United Nations Framework Convention on Climate Change, it appears likely and appropriate that dynamic baselines will be used to evaluate unilateral and supported NAMAs in the transportation sector, providing a potentially valuable role for sketch analysis tools like TEEMP, especially in settings where more robust system evaluation tools may be lacking.

C. Rural Roads Emission Evaluation Model

12. The Rural Road Improvement Model (Figure A3.2) captures the impact of rural road improvements on emissions. It evaluates the impact of widening from single, intermediate lanes to two lanes including roughness improvement. The Microsoft Excel model, Rural Highway Access Improvement.xls, provides a simple tool for CO_2 quantification.

Figure A3.2: Simplified Structure of Roads Model



CO_2 = carbon dioxide.
Source: Independent Evaluation Department.

1. Microsoft Excel Model Structure

13. **User input sheets**:
   (i) input 1: user inputs the majority of inputs,
   (ii) input 2: air pollutant emission factors,
   (iii) traffic: business as usual—traffic with normal growth, and
   (iv) construction.

14. **Output sheet.** Output.

15. **In-built calculation sheets.** Traffic (project-induced), traffic (project + induced, i.e., traffic with normal and induced growth) elasticity, base fuel consumption, capacity, capping limit, revised traffic, particulate matter (PM) factor, PM emission factor, PM emissions, nitrogen oxide (NO_x) factor, NO_x emission factor, NO_x emissions, roughness calculator, speed–fuel factor, fuel consumption, emission factor, vehicle kilometer of travel (VKT), CO_2 (roughness), CO_2 (capacity), CO_2 (capacity + roughness), ##SES (PM), and ##SES (NO_x).

2. Input Data Requirements

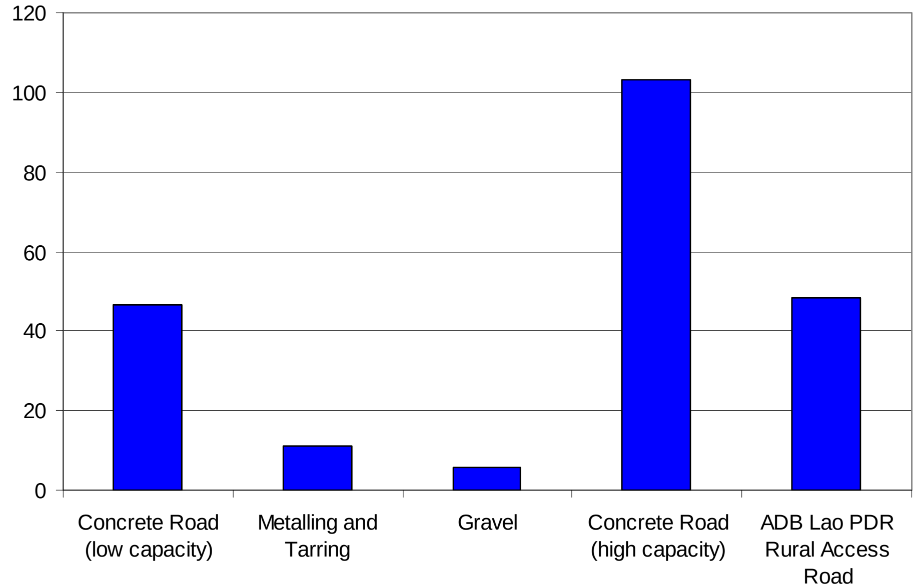
16. Rural road improvement projects are generally less data-intensive, and no advanced traffic modeling is used to justify the traffic projections. These are generally provided to link villages with interconnections and connections with divisional centers and agricultural centers. The emission model shows the impact of such projects. The data requirements are as follows:
   (i) Year: base and project lifetime (20 years).
   (ii) Number of lanes existing and proposed.
   (iii) Length: single project can be subdivided into three sections based on trip lengths and data availability. To see the impact of multiple roads with hundreds of kilometers (km) of corridors, the model needs to be executed a number of times.

(iv) Average trip lengths of each mode: two-wheeler, three-wheeler, passenger car, light commercial vehicle, bus, heavy commercial vehicle (if any), bullock cart, and cycles.
(v) Base year traffic volumes with projections for normal growth.
(vi) Induced traffic elasticity: induced traffic component because of capacity improvement. The elasticity based on the literature review is near 1 (i.e., a 10% increase in lane km would yield a 10% increase in traffic).
(vii) Passenger car units (PCUs) of modes: default values are 0.5 for two-wheelers, 1 for three-wheelers, 1 for passenger cars, 1.5 for light commercial vehicles, 3 for buses, 3 for heavy commercial vehicles, 6 for bullock carts, and 0.5 for cycles.
(viii) Fuel consumption at 50 km speed (liters for 100 km): default value of 2 for two-wheelers, 3.1 for three-wheelers, 10 for passenger cars, 12 for light commercial vehicles, 28 for buses, and 25 for heavy commercial vehicles.
(ix) CO_2 emission factor in kilogram per liter (kg/l) for modes depending on gasoline and diesel fuel split.
(x) Occupancy/loading of each modes.
(xi) Roughness (meter [m]/km) before and after improvement. It is assumed that roughness would be maintained at that level.
(xii) An option is provided for the user to segregate local vs. through traffic.
(xiii) Quantity of cement, steel, and bitumen per km.
(xiv) Average road length of each stretch.
(xv) Rate of annual improvement in fuel economy.
(xvi) Input emission factor for PM (g/km) and NO_x (g/km). To evaluate only the percentage impact on air pollutants, the suggested value is 1.
(xvii) Upstream emission factor to account for fuel manufacture.
(xviii) Volume to capacity (V–C) saturation on a road: the default value is assumed to be 1.5. Roads generally show high travel impedance when the V–C ratio increases to 1.

3. Construction Emissions

17. For emissions generated at the construction stage, two scenarios are provided. The user can either input the construction quantity (i.e., cement, bitumen, and steel) or take a placeholder number based on the literature review (Figure A3.3). The emissions generated during the energy consumption for the production of materials are considered construction emissions and are included in the project analysis. This procedure may result in significant conservative estimates, as emissions generated as a result of materials movement, construction machinery usage, traffic diversion, etc., are not included. Literature review indicates that construction emissions for rural roads are 5 tons/km to 103 tons/km when the full life cycle is considered, depending on the type of treatment.

Figure A3.3: Construction Emissions of Various Types of Rural Roads
(CO_2 [tons]/km)



ADB = Asian Development Bank, CO_2 = carbon dioxide, km = kilometer, Lao PDR = Lao People's Democratic Republic.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports.

4. Operations Emissions due to Capacity Expansion

18. Emissions are dependent on speed, thus using the highway capacity analysis. First, the model establishes the V–C ratios. Using the speed-flow equations from the updated road user cost study[3] (Indian Roads Congress-Special Publication, Manual of Economic Analysis of Highway Projects, India) and the China Green Transport Project,[4] an impact of V–C on speed was quantified. As the V–C exceeds 1, the speed becomes highly variable. It is difficult to determine such speeds using speed-flow equations. For V–C ratios exceeding 1, speed is kept the same as 1 and it needs to be acknowledged that the majority of travel would be a mixture of stop-and-go movements. The traffic projections are curtailed based on maximum saturation criteria and the volume is kept constant after the V–C ratio exceeds the user imputed capping limit.

19. Capacity values considered are 7,200 PCU/day for one-lane highways, 22,800 PCU/day for intermediate lane highways, and 34,500 PCU/day for two-lane highways based on Indian road standards (Table A3.2).

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[3] L.R. Kadiyali et al updated the initial road user cost study of 1982.
[4] Asian Development Bank and Ministry of Transport, People's Republic of China. 2009. *Green Transport: Resource Optimization in the Road Sector in the People's Republic of China*. Manila. Collaborative project. http://www.adb.org/Documents/ Books/Green-Transport/Green-Transport.pdf

Table A3.2: Variation of Volume to Capacity—Speed for Various Road Widths

V–C	2 Lane	1 Lane	1.5 Lane
0.00	60	30	40.0
0.10	59	28	39.7
0.20	56	26	39.0
0.30	52	24	37.7
0.40	47	23	36.0
0.50	41	21	34.0
0.60	34	20	31.7
0.70	29	20	27.0
0.80	24	19	22.5
0.90	22	18	20.0
1.00	22	18	20.0
1.50	22	18	20.0
2.50	22	18	20.0

V–C = volume to capacity.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports.

20. Using a variety of studies[5] on speed and emissions, drive cycle effects were derived. For different speeds, fuel consumption values and air pollutant emission factors were derived, averaged, and selected for user convenience (Table A3.3). If users wish to follow the equations, it is better to reprocess the numbers with actual equations.

Table A3.3: Speed and Emission Factors Index

	Carbon Dioxide						Particulate Matter				Nitrogen Oxide			
Speed	**2W**	**3W**	**Cars**	**LCV**	**Bus**	**HCV**	**Car**	**LGV**	**Bus**	**HGV**	**Car**	**LGV**	**Bus**	**HGV**
15	(70)	(70)	(61)	(69)	(61)	(61)	(43)	(30)	(21)	(60)	(43)	(35)	(56)	(44)
20	(43)	(43)	(34)	(38)	(51)	(51)	(26)	(18)	(16)	(55)	(32)	(23)	(46)	(36)
25	(26)	(26)	(20)	(22)	(39)	(39)	(18)	(10)	(12)	(45)	(23)	(14)	(37)	(28)
30	(21)	(21)	(12)	(18)	(23)	(23)	(11)	(4)	(9)	(35)	(16)	(8)	(29)	(22)
35	(7)	(7)	(5)	(6)	(15)	(15)	(6)	(1)	(7)	(25)	(10)	(3)	(21)	(15)
40	(4)	(4)	(3)	(3)	(9)	(9)	(3)	1	(4)	(16)	(5)	(1)	(14)	(10)
45	(1)	(1)	0	0	(3)	(3)	(1)	1	(2)	(7)	(2)	0	(7)	(4)
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	(1)	(1)	2	2	0	(2)	2	6	1	(2)	6	6
60	(2)	(2)	(3)	(4)	5	5	(1)	(4)	3	10	1	(4)	13	9
65	(4)	(4)	(6)	(7)	5	5	(3)	(8)	3	12	1	(7)	13	9
70	(8)	(8)	(9)	(12)	6	6	(6)	(11)	3	12	(1)	(11)	13	9
75	(12)	(12)	(13)	(16)	0	0	(9)	(15)	1	12	(3)	(15)	10	7
80	(18)	(18)	(18)	(23)	(4)	(4)	(13)	(19)	(1)	10	(5)	(19)	7	4
85	(23)	(23)	(24)	(29)	(7)	(7)	(17)	(23)	(5)	7	(9)	(24)	4	1
90	(30)	(30)	(30)	(37)	(12)	(12)	(22)	(28)	(8)	4	(12)	(28)	1	(2)
95	(37)	(37)	(36)	(45)	(16)	(16)	(27)	(32)	(8)	(14)	(16)	(33)		
100	(37)	(37)	(36)	(45)	(16)	(16)	(32)	(36)	(8)	(16)	(20)	(38)		

( ) = negative, 2W = 2-wheeler, 3W = 3-wheeler, kph = kilometer per hour, HCV = heavy commercial vehicle, LCV = light commercial vehicle.
Note: These figures assume 0 at 50 kilometers per hour, i.e., percent decrease in fuel efficiency assuming fuel efficiency at 50 kilometers per hour as 0.
Source: Independent Evaluation Department estimate based on empirical research.

21. Using the base 50 kilometers per hour (kph) speed emission factors and stream speeds, the model first calibrates the emission factors and then processes CO_2 emissions. Options are included to check the impact of fuel efficiency on CO_2 emissions.

5 COPERT-3, CORINAR, Green Transport, Developing Integrated Emissions Strategies for Existing Land Transport, updated road user cost study, and Transport Research Laboratory (United Kingdom).

22. The model allows users to quantify air pollutants (PM and NO_x) using the emission factors. Air pollutant emission factors of vehicles are adopted from a variety of literature available from various Asian countries, including the Developing Integrated Emissions Strategies for Existing Land Transport (DIESEL) 2008 for Bangkok (Thailand),[6] and the emission factors derived at the Automotive Research Association of India.[7] Other countries could have specific national level emission factors for local projects.

23. The above methodology allows the user to capture the capacity expansion impact on emissions.

5. Operations Emissions caused by Road Riding Quality Improvement (Roughness)

24. Road roughness is the expression of surface irregularity, which affects riding quality and fuel consumption. To evaluate the riding surface improvement projects/maintenance projects on emissions, the model adopts the factors suggested by the Green Transport Project (Table A3.4).

Table A3.4: Impact of Road Roughness on Fuel Consumption

Roughness (m/km)	**Impact on Fuel Consumption**
2	1.00
3	0.99
4	0.98
5	0.98
6	0.97
7	0.96
8	0.95
9	0.95
10	0.94
11	0.93
12	0.92
13	0.92
14	0.91
15	0.90

km = kilometer, m = meter.
Source: Asian Development Bank and Ministry of Transport, People's Republic of China. 2009. *Green Transport: Resource Optimization in the Road Sector in the People's Republic of China*. Manila. Collaborative project. http://www.adb.org/ Documents/Books/Green-Transport/ Green-Transport.pdf

6. Outputs

25. The model also provides the user an opportunity to combine the impacts of capacity expansion and roughness. The analysis is refined for various scenarios such as a business-as-usual case (no improvement), with improvement without considering induced traffic and a scenario with induced traffic. For induced traffic, a simple tool is included to quantify additional traffic caused by the capacity improvement. Researchers have found lane miles to have a statistically significant relationship with vehicle distance traveled. The impact is shown in several studies with elasticity of 0.5 to 1. A default value of 1 has been proposed.

[6] United Nations Development Programme and World Bank Energy Sector Management Assistance Programme. 2008. DIESEL. Bangkok.
[7] See Automotive Research Association of India's website – http://www.araiindia.com/

26. To account for emissions generated during upstream (to manufacture the fuel), a factor of 14% is assumed as a default,[8] and emissions are scaled up appropriately.

D. Urban Roads Emission Evaluation Model

27. The Urban Road Improvement Model captures the impact of urban road improvements on emissions. It evaluates the impact of widening from two lanes to four and six lanes, including roughness improvement. To capture the impact of system management techniques, an option of two-lane one-way streets is included. Figure A3.2 provides the basic structure and the Microsoft Excel model Urban Roads.xls provides a simple tool for CO_2 quantification.

28. This model is applied to both business-as-usual and project scenarios. It segregates the impact of the induced traffic component by providing a simple tool.

1. Microsoft Excel Model Structure

29. **User input sheets:**
(i) input 1: user inputs majority of inputs,
(ii) input 2: air pollutant emission factors,
(iii) traffic: business as usual—traffic with normal growth, and
(iv) construction.

30. **Output sheet.** Output.

31. **In-built calculation sheets.** Traffic (project-induced), traffic (project + induced—traffic with normal and induced growth) elasticity, base fuel consumption, capacity, capping limit, revised traffic, PM factor, PM emission factor, PM emissions, NO_x factor, NO_x emission factor, NO_x emissions, roughness calculator, speed–fuel factor, fuel consumption, emission factor, VKT, CO_2 (roughness), CO_2 (capacity), CO_2 (capacity + roughness), ##SES (PM), and ##SES (NO_x).

2. Input Data Requirements

32. Urban road improvement projects are highly data-intensive, and advanced traffic models are required to justify the traffic projections. The roads modeled are widening of arterial roads development of elevated roads and high capacity ring roads as a part of system management technique to provide immediate traffic congestion release.

33. The data required are as follows:
(i) Year: base and project lifetime (20 years).
(ii) Number of lanes existing and proposed.
(iii) Length: a single project can be subdivided into three sections based on trip lengths and data availability. To see the impact of multiple roads with hundreds of km of corridors, the model needs to be executed a number of times.
(iv) Average trip lengths of each mode: two-wheeler, three-wheeler, passenger car, light commercial vehicle, bus, heavy commercial vehicle (if any), bullock cart, and cycles.
(v) Base year traffic volumes with projections for normal growth.
(vi) Induced traffic elasticity: induced traffic component caused by capacity improvement. The elasticity based on the literature review is near 1 (i.e., a 10% increase in lane km would yield a 10% increase in traffic).

[8] Literature review of various studies, including those from the International Energy Agency and the Clean Development Mechanism, suggests a mid value of 14% as reasonable.

(vii) PCUs of modes: default value of 0.5 for two-wheelers, 1 for three-wheelers, 1 for passenger cars, 1.5 for light commercial vehicles, 3 for buses, 3 for heavy commercial vehicles, 6 for bullock carts, and 0.5 for cycles.
(viii) Fuel consumption at 50 km speed (liters for 100 km): default value of 2 for two-wheelers, 3.1 for three-wheelers, 10 for passenger cars, 12 for light commercial vehicles, 28 for buses, and 25 for heavy commercial vehicles.
(ix) CO_2 emission factor in kg/l for modes depending on gasoline and diesel fuel split.
(x) Occupancy/loading of each mode.
(xi) Roughness (m/km) before and after improvement. It is assumed that roughness would be maintained at that level.
(xii) An option is provided to segregate local vs. through traffic.
(xiii) Quantity of cement, steel, and bitumen per km.
(xiv) Average road length of each stretch.
(xv) Rate of annual improvement in fuel economy.
(xvi) Input emission factor for particulate matter (gram/km) and NO_x (g/km). To evaluate only the percentage impact on air pollutants, the suggested value is 1.
(xvii) Upstream emission factor to account for fuel manufacture.
(xviii) V–C saturation on a road: default value is assumed to be 1.5. Roads generally show high travel impedance when the V–C ratio increases to 1.

3. Construction Emissions

34. For emissions generated at the construction stage, two scenarios are provided. The user can either input the construction quantity (i.e., cement, bitumen, and steel) or take a placeholder number based on a literature review. The emissions generated during the energy consumption for the production of materials are considered construction emissions and are included in the project analysis. This procedure may result in a significant conservative estimate, as emissions generated from material movement, construction machinery usage, traffic diversion, etc., are not included.

4. Operations Emissions caused by Capacity Expansion

35. Emissions are dependent on speed, thus using the highway capacity analysis. First, the model establishes the V–C ratios. Using the insights on speed-flow equations from the updated road user cost study (Indian Roads Congress-Special Publication, Manual of Economic Analysis of Highway Projects), the China Green Transport Project, and the Bangalore Metro Project,[9] an impact of V–C on speed was quantified (Table A3.5). As the V–C exceeds 1, the speed becomes highly variable. It is difficult to determine such speeds using speed-flow equations. For V–C ratios exceeding 1, speed is kept the same as 1 and it needs to be acknowledged that the majority of travel would be a mixture of stop-and-go movements. The traffic projections are curtailed based on maximum saturation criteria and the volume is kept constant after the V–C ratio exceeds the user imputed capping limit.

[9] Independent Evaluation Department analysis based on data from Bangalore Metro project, which is under construction by Bangalore Metro Rail Corporation. http://bmrc.co.in (accessed 14 May 2010).

Table A3.5: Variation of Volume to Capacity – Speed for Various Road Widths

V–C	2 Lane	2 Lane (one way)	4 Lane	6 Lane
0.00	30.00	30.00	50.00	80.00
0.10	29.97	29.97	49.90	79.81
0.20	29.81	29.81	49.43	78.98
0.30	29.40	29.40	48.43	77.31
0.40	28.67	28.67	46.78	74.63
0.50	27.51	27.51	44.38	70.83
0.60	25.85	25.85	41.13	65.80
0.70	23.61	23.61	36.96	59.44
0.80	20.72	20.72	31.80	51.67
0.90	17.09	17.09	25.56	42.41
1.00	15.00	15.00	18.20	31.60

V–C = volume to capacity.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports and empirical research.

36. Capacity values considered are 21,500 PCU/day for two-lane highways, 34,500 PCU/day for two-lane (one-way) highways, 51,500 PCU/day for four-lane highways, and 77,000 PCU/day for six-lane highways based on Indian urban road standards.

37. Using a variety of studies on speed and emissions, drive cycle effects were derived (Figure 7, main text). For different speeds, fuel consumption values and air pollutant emission factors were derived, averaged, and selected for user convenience. To follow the equations, it is better to reprocess the numbers with equations.

38. Using the base 50 kph speed emission factors and stream speeds, the model first calibrates the emission factors and then processes CO_2 emissions. Table A3.5 provides the impact of speed on emissions. Options are included to check the impact of fuel efficiency on CO_2 emissions.

39. The model allows users to quantify air pollutants (particulate matter and NO_x) using the emission factors. The above methodology allows the user to capture the capacity expansion impact on emissions.

5. Operations Emissions caused by Road Riding Quality Improvement (Roughness)

40. Road roughness is the expression of surface irregularity, which affects riding quality and fuel consumption. To evaluate riding surface improvement projects/maintenance projects on emissions, the model adopts the factors suggested by the Green Transport Project. Table A3.4 gives the impact of riding quality on fuel consumption.

6. Outputs

41. The model allows the user to combine the impacts of capacity expansion and roughness. The analysis is refined for various scenarios such as a business-as-usual case (no improvement), with improvement without considering induced traffic, and a scenario with induced traffic. For induced traffic, a simple tool is included to quantify additional traffic caused

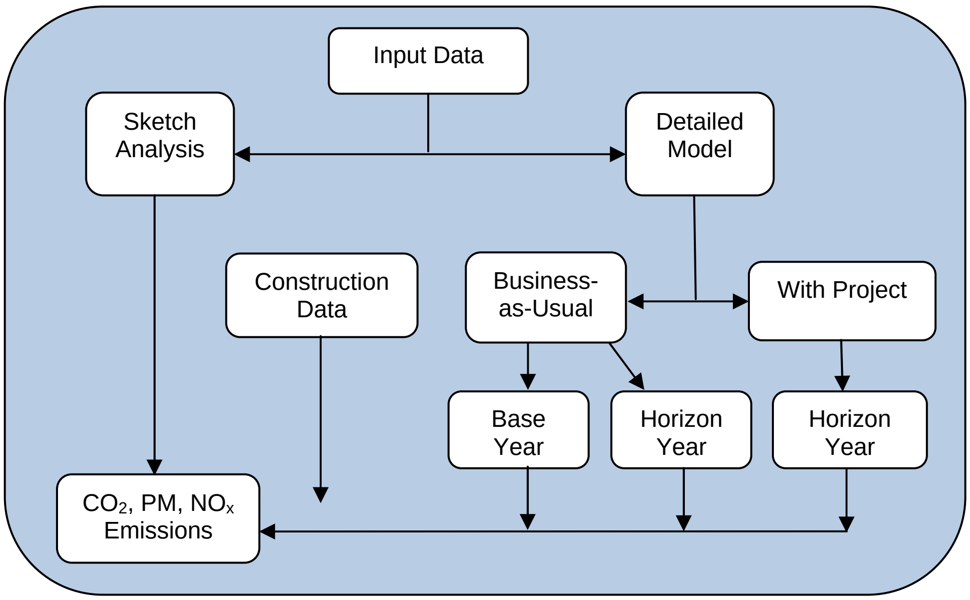
by the capacity improvement. Researchers[10] have found lane miles to have a statistically significant relationship with vehicle distance traveled. The impact is shown in several studies with elasticity of 0.5 to 1. A default value of 1 has been proposed. To account for emissions generated during upstream (to manufacture the fuel), a factor of 14% is assumed as the default and emissions are scaled up appropriately.

E. Nonmotorized Transport (Bikeways) Emission Evaluation Model

42. The NMT project model captures the impact of bikeways on emissions. The Microsoft Excel model, Non Motorized Transport – Bikeways.xls, provides a simple tool for CO_2 quantification.

43. The model provides an option of quantifying the emissions either at the sketch level or at the meso and micro level. Figure A3.4 provides a structure of the model.

Figure A3.4: Simplified Structure of Bikeway Improvement Project Model



CO_2 = carbon dioxide, NO_x = nitrogen oxide, PM = particulate matter.
Source: Independent Evaluation Department.

1. Microsoft Excel Model Structure

44. **User input sheets:**
(i) introduction,
(ii) sketch analysis,
(iii) input 1,
(iv) input 2, and
(v) input 3.

45. **Output sheet.** Emission savings summary and charts.

[10] T. Littman. 2010. Generated Traffic and Induced Travel Implications for Transport Planning. Victoria Transport Policy Institute; R. Noland. 2001. Relationships Between Highway Capacity and Induced Vehicle Travel. Transportation Research A, Vol. 35, No. 1, January, pp. 47–72.

46. **In-built calculation sheets.** CO_2, PM, and NO_x.

2. Input Data Requirements

47. The amount of data available in a bikeway project can vary from minimal to comprehensive. To accommodate the possible large variation in terms of data availability, the model provides two options depending on the type of data available and analysis required:

(i) Sketch analysis inputs: width and length of bikeways; average bicycle trip length (6 assumed as default).

(ii) Detailed model for different scenarios: business-as-usual base year, business-as-usual horizon year, with-project horizon year:

- (a) average mode speeds—cars, two-wheelers, three-wheelers, taxi, bus, jeepney/minibus, walking, and cycling;
- (b) vehicle emission standards for modes;
- (c) fuel type (gasoline and diesel);
- (d) mode share of modes—cars, two-wheelers, three-wheelers, taxi, bus, jeepney/minibus, walking, cycling, and LRT;
- (e) average trip length—cars, two-wheelers, three-wheelers, taxi, bus, jeepney/minibus, walking, and cycling;
- (f) average occupancy;
- (g) fuel consumption at 50 km speed (km per liter);
- (h) quantity of cement, steel, and bitumen per km;
- (i) emission factors for cement, steel, and bitumen per ton (production); and
- (j) CO_2, particulate matter, and NO_x emission factors.

3. Construction Emissions

48. For quantifying the emissions generated at the construction stage, quantities of cement, bitumen, and steel are requested. The emissions generated during the energy consumption for the production of these materials are considered construction emissions and are included in the project analysis. This procedure may result in conservative estimates as emissions generated from material movement, construction machinery usage, traffic diversion, etc., are not included.

4. Sketch Analysis

49. If the user does not have any data on the expected mode share, shift, trip lengths, etc., but needs to assess the likely impact of bikeways, experience gained from case studies of Rio de Janeiro (Brazil) and Bogotá (Colombia) are useful.[11] It is assumed that about 1 km of bikeways would attract 2,173 trips. If narrow bikeways (less than 2 m wide) are constructed, the trips are scaled down by 50%. The average trip length suggested as a default by the model is 6 km and a 90% shift from public and intermediate public transport modes. The user can vary the shifts to quantify the impacts.

5. Detailed Model

50. Using the data supplied by the user and ASIF logic, the model tries to capture emissions for business-as-usual (no intervention) and with-project scenarios. The emission savings are highly dependent on the shift achieved, trip lengths, and stream speeds. Using the base 50 kph

[11] Discussions during the meeting of Scientific and Technical Advisory Panel of the Global Environment Facility Scientific and Technical Advisory Panel 19–21 October 2009. Documents located at http://www.adb.org/documents/events/2009/scientific-technical-advisory-panel/default.asp.

speed emission factors and stream speeds, the model first calibrates the emission factors and then processes the CO_2 emissions. Air pollutants (PM and NO_x) are quantified in a similar manner. Table A3.3 gives the impact of speed on emissions (CO_2, particulate matter, and NO_x).

51. The emissions savings are assumed to be linear. Using the base value and horizon year savings, the model quantifies total emissions during the project lifetime. The emissions are increased by a default of 14% to include the “well-to-tank” effect, i.e., from the source of the fuel to the usage in the vehicles.

52. The outputs are total emissions from scenarios, total savings over lifetime, and tons/km/year savings caused by bikeway construction.

F. Expressway Emission Evaluation Model

53. The expressway model captures the impact of development of high-speed highways on emissions. It evaluates the impact of widening highways from two lanes to four and six lanes, including roughness improvement. The Microsoft Excel model Expressways.xls provides a simple tool for CO_2 quantification. Figure A3.2 gives a simplified structure of the roads model.

1. Microsoft Excel Model Structure

54. **User input sheets:**
- (i) input 1: the user inputs the majority of inputs,
- (ii) input 2: air pollutant emission factors,
- (iii) traffic: business as usual—traffic with normal growth, and
- (iv) construction.

55. **Output sheet.** Output.

56. **In-built calculation sheets.** Traffic (project-induced), traffic (project + induced—traffic with normal and induced growth) elasticity, base fuel consumption, capacity, capping limit, revised traffic, PM factor, PM emission factor, PM emissions, NO_x factor, NO_x emission factor, NO_x emissions, roughness calculator, speed–fuel factor, fuel consumption, emission factor, VKT, CO_2 (roughness), CO_2 (capacity), CO_2 (capacity + roughness), ##SES (PM), and ##SES (NO_x).

2. Input Data Requirements

57. Expressway projects are highly capital intensive, so they require advanced traffic models with accurate projections to justify their feasibility. This model is applicable to such projects where major improvements have been carried out over the existing corridor (e.g., widening from two lanes to four/six lanes).

58. The data requirements are as follows:
- (i) Year: base and project lifetime (20 years).
- (ii) Number of lanes existing and proposed.
- (iii) Length: single project can be subdivided into three sections based on trip lengths and data availability. To see the impact of multiple roads with hundreds of km of corridors, the model needs to be executed a number of times.

(iv) Average trip lengths of each mode: two-wheeler, three-wheeler, passenger car, light commercial vehicle, bus, heavy commercial vehicle (if any), bullock cart, and cycles.
(v) Base year traffic volumes with projections for normal growth.
(vi) Induced traffic elasticity: induced traffic component caused by capacity improvement. The elasticity based on the literature review is near 1 (i.e., a 10% increase in lane km would yield a 10% increase in traffic).
(vii) PCUs of modes: the default value is 0.5 for two-wheelers, 1 for three-wheelers, 1 for passenger cars, 1.5 for light commercial vehicles, 3 for buses, 3 for heavy commercial vehicles, 6 for bullock carts, and 0.5 for cycles.
(viii) Fuel consumption at 50 km speed (liters for 100 km): the default value is 2 for two-wheelers, 3.1 for three-wheelers, 10 for passenger cars, 12 for light commercial vehicles, 28 for buses, and 25 for heavy commercial vehicles.
(ix) CO_2 emission factor in kg/l for modes, depending on the gasoline and diesel fuel split.
(x) Occupancy/loading of each mode.
(xi) Roughness (m/km) before and after improvement. It is assumed that roughness would be maintained at that level.
(xii) An option is provided to segregate local vs. through traffic.
(xiii) Quantity of cement, steel, and bitumen per km.
(xiv) Average road length of each stretch.
(xv) Rate of annual improvement in fuel economy.
(xvi) Input emission factor for PM (g/km) and NO_x (g/km). To evaluate only the percentage impact on air pollutants, the suggested value is 1.
(xvii) Upstream emission factor to account for fuel manufacture.
(xviii) V–C saturation on a road – the default value is assumed to be 1.5. Roads generally show high travel impedance when the V–C ratio increases to 1.

3. Construction Emissions

59. For emissions generated at the construction stage, two scenarios are provided. The user can either input the construction quantity, i.e., cement, bitumen, and steel, or take a placeholder number based on the literature review. The emissions generated during the energy consumption for the production of materials are considered construction emissions and are included in the project analysis. This procedure may result in significant conservative estimate, as emissions generated from material movement, construction machinery usage, traffic diversion, etc., are not included.

4. Operations Emissions caused by Capacity Expansion

60. Emissions are dependent on speed, thus using the highway capacity analysis. First, the model establishes the V–C ratios. Using the speed-flow equations from the updated road user cost study, the Bangalore Metro Project, and the China Green Transport Project, an impact of the V–C on speed was quantified (Table A3.6). As the V–C exceeds 1, the speed becomes highly variable. It is difficult to determine such speeds using speed-flow equations. For V–C ratios exceeding 1, speed is kept the same as 1 and it needs to be acknowledged that the majority of travel would be a mixture of stop-and-go movements. The traffic projections are curtailed based on maximum saturation criteria, and the volume is kept constant after the V–C ratio exceeds the user imputed capping limit.

61. Capacity values considered are 34,500 PCU/day for two-lane highways, 80,000 PCU/day for four-lane highways, and 120,000 PCU/day for six-lane highways based on Indian standards.

Table A3.6: Variation of Volume to Capacity – Speed for Various Road Widths

V–C	2 Lane	4 Lane	6 Lane
0.0	60	80	100
0.1	60	80	100
0.2	60	79	99
0.3	59	77	97
0.4	57	75	93
0.5	55	71	89
0.6	52	66	82
0.7	47	59	74
0.8	41	51	65
0.9	34	41	53
1.0	18	29	40
1.5	15	20	25
2.5	15	15	20

V–C = volume to capacity.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports, and empirical research.

62. Using a variety of studies (footnote 5) on speed and emissions, drive cycle effects were derived. For different speeds, fuel consumption values and air pollutant emission factors were derived, averaged, and selected for user convenience. To follow the equations, it is better to reprocess the numbers with actual equations.

63. Using the base 50 kph speed emission factors and stream speeds, the model first calibrates the emission factors and then processes the CO_2 emissions. Options are included to check the impact of fuel efficiency on CO_2 emissions. Table A3.3 provides the impact of speed on emissions.

64. The model allows the user to quantify air pollutants (PM and NO_x) using the emission factors.

65. The above methodology allows the user to capture the capacity expansion impact on emissions.

5. Operations Emissions caused by Road Riding Quality Improvement (Roughness)

66. Road roughness is the expression of surface irregularity, which affects riding quality and fuel consumption. To evaluate riding surface improvement projects/maintenance projects on emissions, the model adopts the factors suggested by the Green Transport Project. Table A3.4 gives the impact of riding quality on fuel consumption.

6. Outputs

67. The model also allows the user to combine the impacts of capacity expansion and roughness. The analysis is refined for various scenarios such as the business-as-usual case (no improvement), with improvement without considering induced traffic, and a scenario with induced

traffic. For induced traffic, a simple tool is included to quantify additional traffic caused by capacity improvement. Researchers have found lane miles to have a statistically significant relationship with vehicle distance traveled. The impact is shown in several studies with elasticity of 0.5 to 1. A default value of 1 has been proposed.

68. To account for emissions generated during upstream (to manufacture the fuel), a factor of 14% is assumed as the default and emissions are scaled up appropriately.

G. Metro Rail Transit Emission Evaluation Model

1. Methodologies Available

69. Several researchers have quantified emissions from MRT using various kinds of methodologies. Prominent methodologies/case studies include the following:

(i) Japan Bank for International Cooperation methodology[12] – considers MRT operation emissions from electricity consumption and modal shift with 100% reduction.

(ii) American Public Transportation Association (APTA) Model[13] – transit agency specific model that can be used either at agency level or at regional level. It uses land use and mode shift factors.

(iii) Clean Development Mechanism Methodology – high data-intensive methodology but neglects construction emissions. Congestion impact beyond MRT corridors not accounted for but includes the emissions for trips from and to MRT stations.

(iv) Simple Interactive Model for better air quality[14] – considers co-benefits as it quantifies air pollutants with CO_2. Considers modal shift only with various scenarios.

2. Methodology Adopted

70. The MRT emissions model captures the impact of MRT systems on CO_2 emissions by quantifying the construction, operation, and traffic impacts of projected MRT users from feasibility studies and actual surveys. Figure A3.5 provides a simplified structure. The Microsoft Excel Urban transport MRT.xls provides the spreadsheet model.

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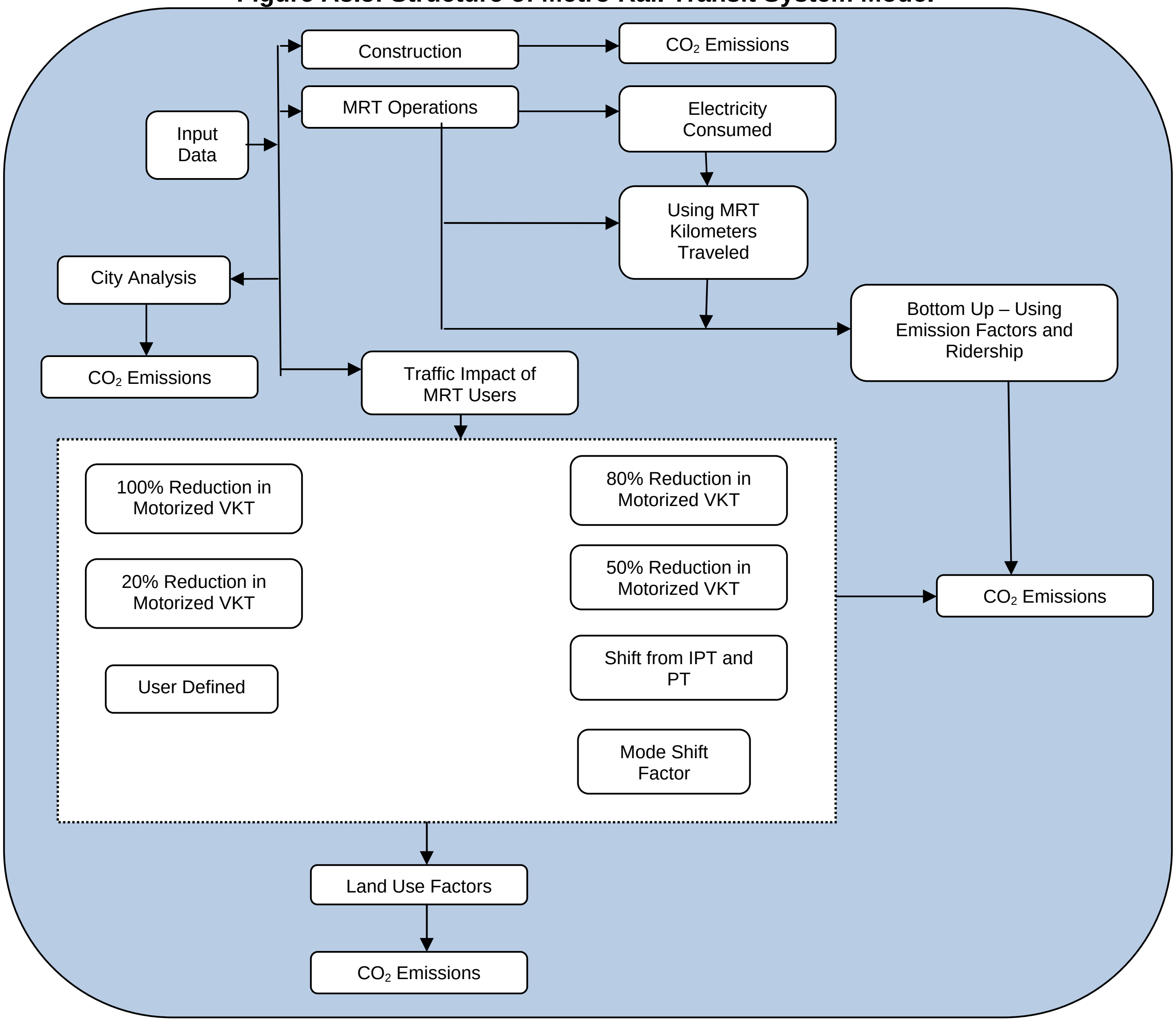
[12] Japan Bank for International Cooperation presentation on 18 March 2008. *Cobenefit of Urban Railway Development Funded by Japanese ODA Loans Addressing Climate Change*. Third Regional Environmentally Sustainable Transport Forum. Singapore.

[13] APTA Climate Change Working Group. 2009. *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit*. APTA Reference CC-RP-001-09.

[14] S. Guttikunda. 2010. *Estimated Air Pollution & Health Benefits of Metro System in Delhi, India*. Simple Interactive Models (SIM) for Better Air Quality. SIM-air working paper series 32-2010.

Figure A3.5: Structure of Metro Rail Transit System Model



CO_2 = carbon dioxide, IPT = intermediate public transport, MRT = metro rail transit, VKT = vehicle kilometer of travel, PT = public transport.
Source: Independent Evaluation Department.

a. Excel Model Structure

71. **User input sheets.** Input.

72. **Output sheet.** Output and graph.

73. **In-built calculation sheets.** Construction, emission factor, MRT (top-down), MRT (bottom-up), shift-motorized (100%), mode shift factor, land use impact (city), shift-motorized (80%), shift-motorized (50%), shift-motorized (20%), shift-motorized (public transport + intermediate public transport), shift-motorized (user), and impact on city.

b. Input Data Requirements

74. The input data requirements are
   (i) construction materials – steel, cement, and bitumen;
   (ii) emission factor – g/passenger-km;
   (iii) electricity grid mix for calculation emissions from MRT;
   (iv) electricity consumption (megawatt-hour) by MRT;
   (v) ridership (base, intermediate, and future year);
   (vi) trip length of MRT users;
   (vii) length of MRT line;
   (viii) average stream speed;
   (ix) fuel economy annual yearly improvement (%);
   (x) fuel economy (km per liter measured at 50 kph speed) at base year;
   (xi) upstream effect of emissions as a result of fuel production;
   (xii) gasoline and diesel emission factors;
   (xiii) mode share of MRT users in business-as-usual case;
   (xiv) average trip length of modes in business-as-usual case;
   (xv) average occupancy of modes in business-as-usual case;
   (xvi) city trip characteristics;
   (xvii) fuel split % of vehicles;
   (xviii) motorized mode shift factor; and
   (xix) land use factor.

c. Construction Emissions

75. MRT construction includes highly energy-intensive processes and should not be neglected at any stage. The model provides a literature review of construction quantity and emissions from a variety of studies and provides the user the option to select the probable one. If the user has data for the construction materials—cement, steel, and bitumen—then, emissions can be directly quantified instead of using approximate placeholder values.

d. Operations Emissions

76. MRT operation emissions need to be quantified from the electricity consumed to operate the MRT. The grid characteristics, electricity consumed, number of MRT runs, and ridership can be used in a variety of top-down and bottom-up processes to quantify the MRT emissions:
   (i) Electricity consumed and its projections can be quantified to generate the emissions.
   (ii) If the electricity consumption values are not available, using the MRT km traveled and using electric power consumption rates for the LRT/MRT, the MRT operation emissions can be quantified.
   (iii) In case only ridership projections, average trip length are available, the user can select an appropriate emission factor based on the literature review. The importance of occupancy levels needs to be acknowledged when selecting the emission factors (g/passenger-km).
   (iv) If two of the above are available, then not only the quantification and comparisons can be made, but it is also possible to generate specific emission factors for the project.

e. Quantification of Emissions Saved

77. The logic behind this quantification is simple. People using MRT because of the project would have used other modes in the business-as-usual scenario, so there would be changes in the emissions. The analysis, however, can be done across different geographical boundaries—across MRT users and citywide impact.

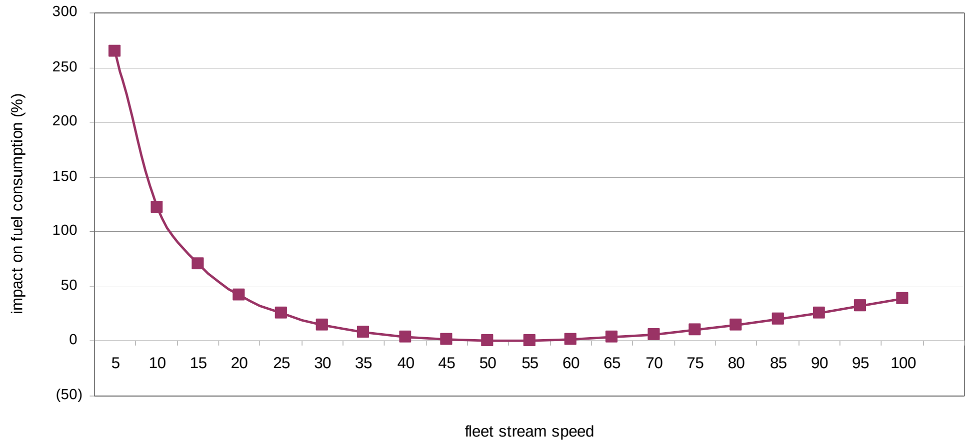
f. Analysis Based on MRT Users

78. The boundary is fixed across the MRT riders only. Using the mode share, trip characteristics such as length, occupancy, stream speeds, etc., and using ASIF logic, emissions are quantified. It is recommended to adopt the average trip lengths of MRT trips as the basis of quantification. For example, if MRT riders travel for an average distance of 6 km, and in the alternate case users would have used private modes (e.g., two-wheelers) for a length of 9 km, the trip length of 6 km is considered for analysis. This assumption neglects the trip to and from the MRT stations to simplify the analysis and data needed for the analysis. Further, the MRT riders before the MRT construction may not have made the trip or the vehicles that they used earlier to make the trip are still being used after the MRT has been constructed or only the people from buses and intermediate public transport have shifted. To capture all these aspects, many pathways are constructed, such as the following:

(i) Shift results in business-as-usual case of a 100% reduction in motorized VKT of the passengers using MRT.
(ii) Shift results in business-as-usual case of 80% reduction in motorized VKT of the passengers using MRT.
(iii) Shift results in business-as-usual case of 50% reduction in motorized VKT of the passengers using MRT.
(iv) Shift results in business-as-usual case of 20% reduction in motorized VKT of the passengers using MRT.
(v) Shift results in business-as-usual case of transfer from only public transport and intermediate public transport.
(vi) Using mode shift factors-based, i.e., percentage of motorized transport of MRT users who would use motorized transport in the absence of MRT. A default value of 0.472 based on the APTA model is proposed.
(vii) User defined shift based on traffic surveys and models. This scenario would capture the exact shift.

79. The upstream effect of emissions caused by fuel production is captured by using a default value of 14%. The impact of average stream speed is captured on emission factors using insights from various studies such as the COPERT, Green Transport, and DIESEL project (footnotes 15 and 31 of the main text and footnote 2 of Appendix 3). Figure A3.6 shows the impact of stream speed on fuel consumption, which is directly correlated with carbon emissions.

Figure A3.6: Impact of Fleet-Stream Speed on Fuel Consumption



kph = kilometer per hour.
Source: Independent Evaluation Department estimate based on empirical research.

g. Impact on the City

80. Using advanced traffic models, which not only capture the operation plan changes but also the changes in stream speeds, mode shares, occupancies, trip lengths, etc., helps in quantifying emissions at the city level.

81. If such models are not available, using the land use factor simulates the impacts caused by an increase in high-density zones as a result of MRT development, which reduces trip lengths, increases nonmotorized trips, etc. Research by APTA suggests a default value of 1.9 in the absence of data.

H. Bus Rapid Transit Emission Evaluation Model

82. In more than 70 cities in Asia, BRT system development is at various stages but only a few have quantified CO_2 emissions. Literature review suggests savings primarily from
- (i) improved public transport vehicles,
- (ii) modal shift from private automobiles,
- (iii) compact development, and
- (iv) operational efficiency improvement.

83. Some of the methodologies/notable examples developed to quantify emissions from the BRT system are
- (i) AM0031 – Methodology for BRT projects,
- (ii) NM0229 – MRT projects,
- (iii) APTA model for transit agencies, and
- (iv) Wright and Fulton BRT framework based on ASIF.

84. Literature suggests that the BRT system projects have high co-benefits when properly designed, executed, and monitored. A Clean Development Mechanism monitoring report of the TransMilenio Project in Columbia showed the extent and distribution of savings (Table A3.7).

Table A3.7: TransMilenio Emission Savings

Description	Emissions	
Baseline emissions	96,902	tCO_2e
Project emissions	(37,881)	tCO_2e
Leakage caused by construction	(5,481)	tCO_2e
Leakage caused by scrapping	(3,010)	tCO_2e
Leakage caused by reduced upstream emissions of fuel saved	8,263	tCO_2e
Leakage caused by reduced congestion	1,829	tCO_2e
Sulfur dioxide	46	tons
Nitrogen oxide	1,838	tons
Particulate matter	243	tons

tCO_2e = ton per carbon dioxide equivalent. Figures in brackets show the incremental emissions.
Source: TransMilenio. 2006. *BRT Bogotá, Colombia: TransMilenio Phase II–IV* Clean Development Mechanism Project Design Document Form prepared by Grutter Consulting. Bogota, Columbia.

85. The emissions quantified from the Metrobus Project in Mexico are summarized in Table A3.8. This shows that the impact is evenly distributed. Contrary to TransMilenio findings, it shows that alternative traffic improvements can have high impact on carbon emissions.

Table A3.8: Mexico Metrobus Project Emissions

Activity Description	Tons of CO_2
Modal shift from cars on the route to buses	15,610
Improving the operating conditions for other vehicles operating on the main route	17,515
Operating condition improvements and/or the substitution of the number and technology of buses that operate on the main route or BRT corridor	17,554
Extra buses required because of the modal shift from cars, metro, or other more fuel-efficient transport to buses on the BRT corridor plus rebound and new trip creation on the buses	2,996
Elimination of left turns on the route or BRT corridor generates increased travel time and distance for those vehicles that now have to go around the block	693
Longer distance required for vehicles to cross the corridor because of the elimination of crossing points in the with-project case	0
Longer time required for vehicles to cross the route or BRT corridor because traffic signal timing is altered, giving priority to buses	543
Detours during construction (one time)	2,685
Greenhouse gas emissions caused by construction activities of the project and energy used to produce the construction materials	67,774

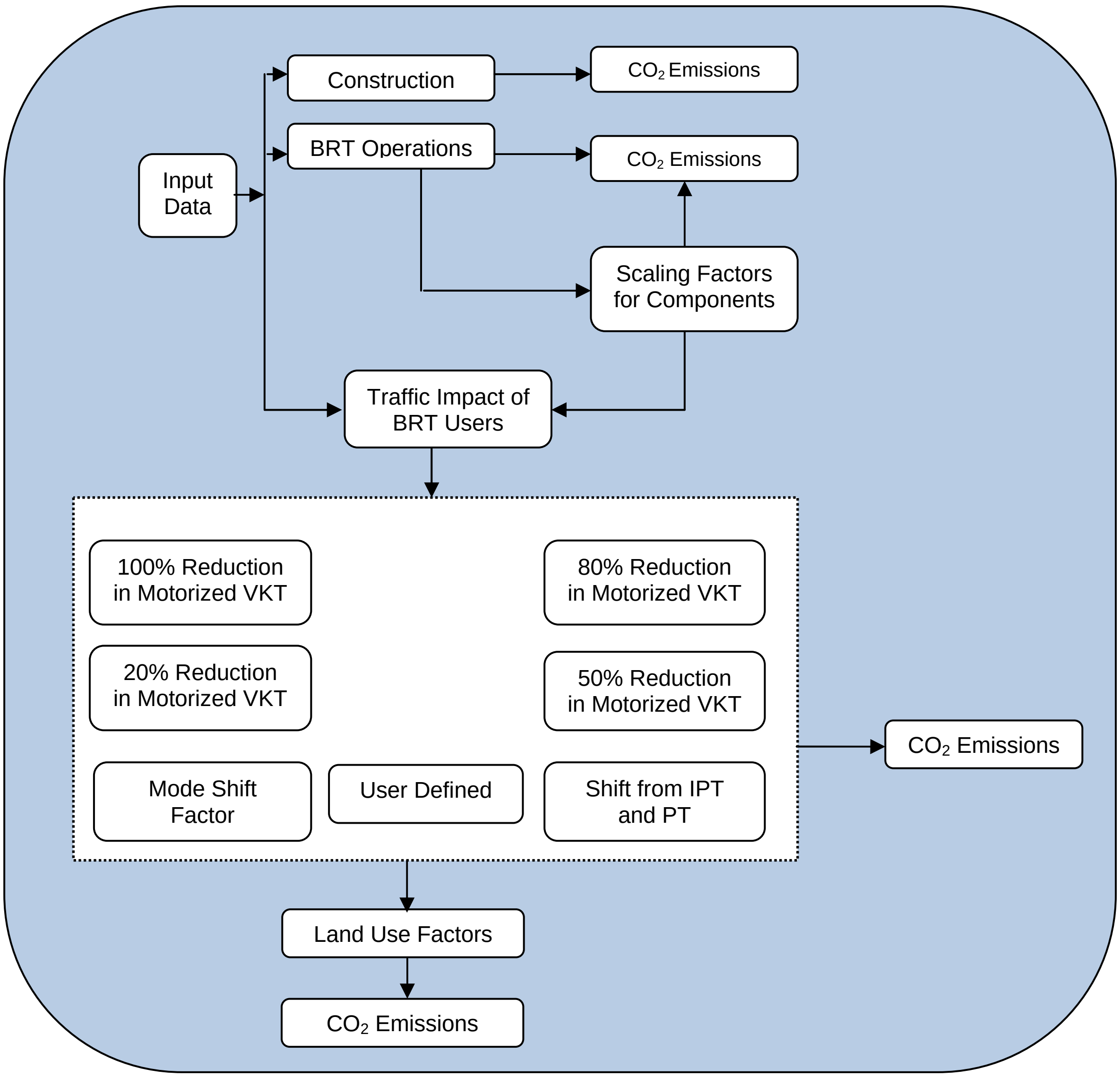
BRT = bus rapid transit, CO_2 = carbon dioxide.
Source: Schipper et al. 2010. *Carbon Dioxide Emissions from Urban Road Transport in Latin America: CO_2 Reduction as a Co-benefit of Transport Strategies.* Transportation Research Board Annual Meeting 2010 Paper #10-3832.

86. The network effect can generate high induced traffic, which is difficult to access as many developing countries have single vehicle ownerships. Thus, the BRT system has resulted in citywide impacts that are difficult to quantify.

87. To devise a methodology for CO_2 measurement from BRT system projects for ADB, insights from various studies were borrowed and a Microsoft Excel spreadsheet model (Urban transport – BRT.xls) was developed based on ASIF methodology.

88. The BRT emissions model captures the impact of BRT system on CO_2 emissions by quantifying the construction, operation, and traffic impacts of projected BRT users from feasibility studies and actual surveys. Figure A3.7 illustrates the simplified structure.

Figure A3.7: Structure of Bus Rapid Transit Model



BRT = bus rapid transit, CO_2 = carbon dioxide, IPT = intermediate public transport, PT = public transport, VKT = vehicle kilometer of travel.
Source: Independent Evaluation Department.

1. Microsoft Excel Model Structure

89. **User input sheets.** Basic, speed, tech%, fuel type, occupancy, fuel efficiency at 50 kph, mode share, trip length, BRT system-basic, components, fleet fuel, factors, passenger-km traveled mode share, and construction.

90. **Output sheets.** #Graph, CO_2, PM, and NO_x.

91. **In-built calculation sheets.** Construction, BRT system-SF+MF, BRT operation, shift-motorized (100%), shift-motorized (100%) PM, mode shift factor, BRT system impact of SF, 80% scenario, 50% scenario, 20% scenario, intermediate public transport-public transport scenario, user-defined, shift-motorized (100%) NO_x.

2. Input Data Requirements

92. These are as follows:
- (i) construction materials – steel, cement, and bitumen;
- (ii) ridership (base, intermediate, and future year);
- (iii) trip length of BRT users;
- (iv) length of BRT line;
- (v) average speed of modes;
- (vi) fuel economy annual yearly improvement (%);
- (vii) fuel economy (km per liter measured at 50 kph speed) at base year;
- (viii) upstream effect of emissions caused by fuel production;
- (ix) gasoline and diesel emission factors;
- (x) mode share of BRT users in business-as-usual case;
- (xi) emission factors for particulate matter and NO_x;
- (xii) average trip length of modes in business-as-usual case;
- (xiii) average occupancy of modes in business-as-usual case;
- (xiv) city trip characteristics;
- (xv) fuel split percentage of vehicles;
- (xvi) technology split percentage;
- (xvii) motorized mode shift factor;
- (xviii) public transport and intermediate public transport mode shift factor;
- (xix) land use factor; and
- (xx) BRT system—component information—running ways, stations, vehicles, service patterns, Intelligent Transportation System application, and BRT branding.

3. Construction Emissions

93. BRT construction emissions account for the emissions generated during material production and construction of infrastructure such as additional lanes, stations, etc. Model provides a literature review of construction quantity and emissions from a variety of studies and allows the user to select the probable one. If the user has data on construction materials (cement, steel, and bitumen), emissions can be directly quantified instead of using approximate placeholder values.

4. Operations Emissions

94. The modus operandi of BRT measurement methodology is to measure the operation emissions from the BRT system fleet using emission factors, occupancies, ridership, speeds, etc., for base, intermediate, and future years. The base emission factors are varied according to speed to generate emissions. PM and NO_x emissions are quantified in a similar manner. Table A3.3 provides the impact of speed on emissions.

95. To evaluate the impact of such a BRT system, which includes all the components, a complete BRT system was compared with an incomplete BRT system from an emissions perspective. Using insights from the Institute for Transportation and Development Policy's BRT design guide and its working experience on Asian BRT systems, a concept of ridership

depreciation is proposed to observe the impacts of various components on emissions (Table A3.9).

Table A3.9: Components of a Complete Bus Rapid Transit System

Bus Rapid Transit System Characteristic	Description	System Score
1. Road Works		
1a. Infrastructure: Cross section/right-of-way	*Dedicated right-of-way in central verge, with barrier*	*7*
1b. Infrastructure: station/junction relation	Station separated from junction by minimum of 70 meters	3
1c. Roadworks at station	Passing lanes at station stops if passengers per hour per direction >6,000	8
2. Bus Stations		
2a. Station design	Unique/attractively designed shelter	1
	Weather protection at stations	1
	Illumination	1
	Security personnel at stations	2
	Stations =>3.5 meters wide	3
2b. Stations: Bus docking interface	Multiple docking bays with space to pass if passengers per hour per direction > 6,000	6
	3 or more doors	4
	Boarding platform level with bus floor	8
2c. Station accessibility	*Safe and attractive pedestrian access system and corridor environment*	3
	Bicycle parking at stations	1
	Bicycle stations/bicycle rentals/public bicycles at stations	1
	Compliant with Access Exchange International BRT Accessibility guidelines	1
	Bikeways paths leading to stations	1
3. Operations	*Service offered throughout day*	3
	High frequency service < 5 minutes average	3
	Off-vehicle fare collection	8
	On-bus camera enforcement of right-of-way	2
	Turning restrictions across > 60% of intersections (high volume) or bus priority at junctions (low volume)	5
	Operational control system to reduce bus bunching	5
	Extensive feeder bus services integrated into bus rapid transit	5
	Integrated fare collection with other public transport	5
	Peak-period pricing	4
	Performance-based contracting for operators	5
4. Passenger information and branding	Passenger information at stops, headway > 5-minute information on vehicles	2
	Quality branding of vehicles and stations	1
	Brochures/schedules	1

Source: Adapted from W. Hook. 2010. Institute for Transportation and Development Policy. Independent analysis for United Nations Environment Programme (February). New York. Unpublished.

5. Emissions Saved

96. If the BRT had not been constructed, users would have been forced to use the existing modes, so the emissions saved result from quantifying the business-as-usual case of the proposed BRT riders. Thus, the boundary of quantification is fixed across the BRT riders only.

97. It is recommended to adopt the average trip lengths of BRT trips as the basis of quantification. For example, if BRT riders travel for an average distance of 6 km and in the alternate case, the users would have used private modes (e.g., two-wheelers) for a length of 9 km, the trip length of 6 km is considered for analysis. This assumption neglects the trip to and from the BRT stations to simplify the analysis and data needed for the analysis. Further, the BRT

riders may not have made the trip before construction of the BRT, or the vehicles they used earlier to make the trip are still being used after the BRT has been constructed or only the people from buses and intermediate public transport have shifted. To capture all these aspects, many pathways[15] are constructed:

(i) Shift results in business-as-usual case of 100% reduction in motorized VKT of the passengers using BRT.
(ii) Shift results in business-as-usual case of 80% reduction in motorized VKT of the passengers using BRT.
(iii) Shift results in business-as-usual case of 50% reduction in motorized VKT of the passengers using BRT.
(iv) Shift results in business-as-usual case of 20% reduction in motorized VKT of the passengers using BRT.
(v) Shift results in business-as-usual case of transfer from only public transport and intermediate public transport.
(vi) Using mode shift factors-based, i.e., percentage of motorized transport of BRT users who would use motorized transport in the absence of BRT.
(vii) User-defined shift based on traffic surveys and models. This scenario would capture the exact shift.

98. The impact on other traffic is neglected because of the induced component. Inclusion of this aspect would require not only data heavy traffic modeling but also citywide additional surveys and the accuracy would still depend on several network factors.

99. The logic behind neglecting this aspect is that such benefits are not quantified in vehicle operating costs and travel time savings during the feasibility stage, which have greater economic value than CO_2 savings. It may not be justifiable to conduct citywide surveys just for the quantification of CO_2 benefits.[16] To account for such impacts on traffic and land use, the land use factor may be adopted.[17] APTA methodology considers a factor of 1.9 as reasonable, and this value can be refined based on experience.

100. The analyst should change the mode shares to favor private transport in the intermediate and horizon year, based on motorization of the fleet, when quantifying the business-as-usual case.

101. The upstream effect of emissions caused by fuel production is captured by using a default value of 14%. The impact of speed is captured on emission factors using insights from various studies such as COPERT, Green Transport, and DIESEL project.

[15] The Institute for Transportation and Development Policy research indicates a consistent shift of only 10%–20% from private automobiles based on review of BRT systems in Bogotá (Colombia), Curitiba (Brazil), Jakarta (Indonesia), and other cities.

[16] In the BRT (Metrobús) project in Mexico City, if CO_2 is valued even at $85 per ton, the CO_2 co-benefits add almost $4 million to the total, and the CO_2 is worth about 20% of the total project benefits. See L. Schipper, E. Deakin, C. McAndrews, L. Scholl, K T Frick. 2009. *Considering Climate Change in Latin American and Caribbean Urban Transportation: Concepts, Applications, and Cases*. Center for Global Metropolitan Studies, University of California, Berkeley.

[17] Research by APTA suggests a value of 1.9 as a placeholder. Its vehicle-mile reductions per passenger mile recommended practice for quantifying greenhouse gas emissions from transit.

I. Railways Evaluation Model

1. Microsoft Excel Model Structure

102. **User input sheets.** Home, choice, basic, passenger and freight data, emission factor and construction, and output sheets—summary, in-built calculation sheets named as construct ghost, rail highway ghost.

2. Input Data Requirements

103. The input data requirements are:
(i) base year;
(ii) passenger-km or ton-km;
(iii) number of passengers and average trip lengths;
(iv) emission factor—g/passenger-km traveled, megajoules (MJ)/passenger-km or MJ/ton-km; and
(v) Quantity of construction materials—number of rails per km, weight of rails per km, number of sleepers per km, number of fish plates per km of track, number of fish bolts per km of track, number of bearing plates per km of track, number of dog-spikes per km of track, quantity of ballast required for broad gauge, number of stations and bridges, quantity of steel, concrete and copper, etc.

3. Construction Emissions

104. Railway construction emissions should ideally account for the emissions generated during material production and construction of infrastructure such as tracks, stations, etc. The model allows the user to select the methodology to calculate construction emissions appropriate to the data available. The methodology choices are as follows:
(i) use default value;
(ii) calculate using quantity of intermediate products used of rails per km, weight of rails per km, number of sleepers per km, number of fish plates per km of track, number of fish bolts per km of track, number of bearing plates per km of track, number of dog-spikes per km of track, and quantity of ballast required for broad gauge;
(iii) Using quantity of steel, concrete, and copper; and
(iv) Option for accounting for construction emissions of non-track facilities—stations, hydraulic structures, electric infrastructure, use of machinery, etc.

105. At many locations, defaults have been proposed to assist the user in quantifying the emissions.

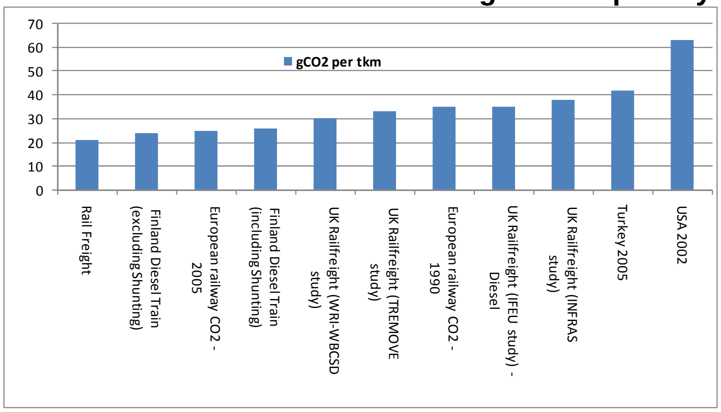
4. Operations Emissions

106. To compare transport modal alternatives, a sketch evaluation model for railways has been developed. This spreadsheet model requires activity data and emission factors in g/passenger-km (g/ton-km) or MJ/passenger-km (ton-km). It allows the user to compare the emissions generated by railways operation against highway operation. If the user does not have national estimates of emission factors for region-specific railways, default numbers based on literature review have been provided which provide a reasonable understanding of the magnitude of emissions exceeded or saved by building railway infrastructure. The analyst may

see emissions quantified based on a high and low levels, indicating various degrees of efficiency based on an international literature review.

107. Figure A3.8 illustrates a literature review of existing railway emission factors collected from different sources.

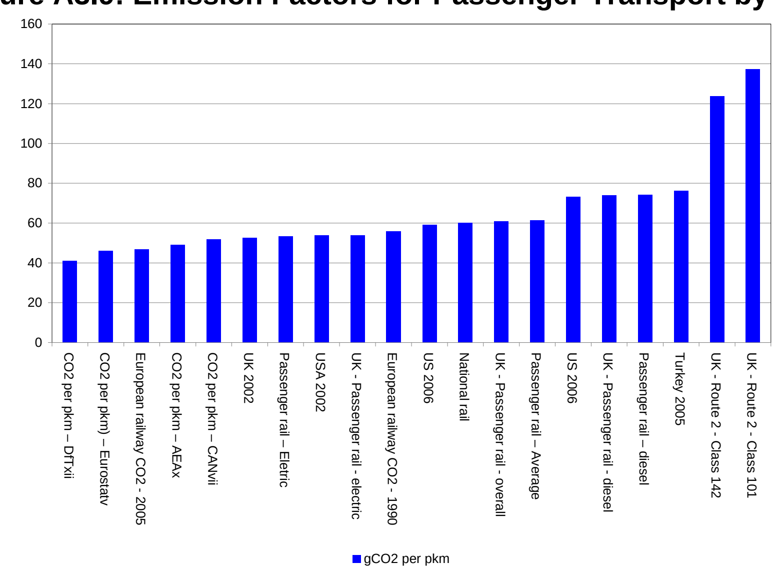
Figure A3.8: Emission Factors for Freight Transport by Rail



CO_2 = carbon dioxide, UK = United Kingdom, USA = United States of America.
Source: Independent Evaluation Department estimate based on literature review.

108. Default values of 130 g/passenger-km (high level of efficiency) and 45 g/passenger-km (low level of efficiency) are provided for passenger transport, and 63 g/ton-km (high level of efficiency) and 21 g/ton-km (low level of efficiency) are provided for freight transport (Figure A3.9).

Figure A3.9: Emission Factors for Passenger Transport by Rail



CO_2 = carbon dioxide, pkm = passenger-kilometer, UK = United Kingdom, USA = United States of America.
Source: Independent Evaluation Department estimate based on literature review.

109. This model will need to be refined in future with scenario analysis based on various degrees of shift and linked with the expressway emission evaluation model for better comparison.

DATA CONSTRAINTS IN CARBON EMISSIONS MEASUREMENT

1. The majority of the data required for emission quantification is already collected at the appraisal of most transport projects for computing road user costs and benefits. The input parameters required for the transport emissions evaluation model for projects developed as part of this evaluation knowledge brief capture dynamic baselines with changes[1] in transport activity and greenhouse gas emissions intensity, attributable to the investments made during the project's supervised implementation period.

2. To forecast the emissions, it is important to collect the following data, which is common across projects in a city or country:

(i) Vehicular mix with ageing details (scrappage);
(ii) Current and future emissions standards for air pollutants;
(iii) Region-specific emission factors; and
(iv) Future policies on traffic and transportation such as fuel economy, alternate fuels, etc.

3. There is a need to improve and make consistent the methods of collecting data at the project feasibility and design stages. Several Asian countries do not collect the vehicle activity data at country level, as it is an iterative, elaborate, and costly process. Table A4 shows the constraints in the availability of data. Non-availability of data, such as the vehicle technology split and emission factor for particulate matter (gram/kilometer) and nitrogen oxide (gram/kilometer), leads to reliance on assumptions. This could result in distortions in the accuracy of the carbon emissions estimate.[2]

[1] J. Rogers. 2009. *Assessment of GHG Mitigation from Land Transport Projects*. Manila. Document located at http://www.adb.org/Documents/Events/2009/Scientific-Technical-Advisory-Panel/Methodology.pdf

[2] S. Gota and B. Fabian. 2009. *Estimating Emissions from Land Transport at Country, City and Project Levels – a critical look at theory and practice*. Manila. Document located at - http://www.adb.org/Documents/Events/2009/Scientific-Technical-Advisory-Panel/Gota-Fabian.pdf

Table A4: Constraints in the Availability of Data

Data	Data Available in ADB's RRP or PCR?	Data Assumed by the TEEMPs
Number of lanes existing and proposed for roads/BRT system and length of road/MRT line	Yes	
Base year traffic volumes with projections for normal growth for roads (ridership for MRT/BRT systems)	Yes	
Induced traffic elasticity/growth	Available in some cases but not always	Assumed from literature survey
Fuel consumption at 50 km speed (km per liter)	No	Assumed from literature survey
Average mode speeds	Available in some cases but not always	Calculated using speed-flow equations
Average trip lengths of each mode	Available in some cases but not always	Assumed based on section lengths
Occupancy/loading of each mode	Available in some cases but not always	Assumed based on sample corridors
Roughness (m/km) before and after improvement	Available in some cases but not always	Assumed from literature survey
Quantity of cement, steel, and bitumen/km for construction	Available in some cases but not always	Assumed from SARD model/ sample corridor/literature review
Rate of annual improvement in fuel economy	No	Assumed from literature survey
Vehicle technology split – Euro I, Euro II, etc. (for calculation of air pollutants)	No	Assumed from literature survey
Emission factor for particulate matter (g/km) and NO_x (g/km) (for calculation of air pollutants)	No	Assumed from literature survey
Trip mode share in case of urban transport projects	Yes	
Mode shift details	Available in some cases but not always	Assumed from literature survey
Electricity grid mix for calculation of emissions from MRT systems	No	Assumed from literature survey
Electricity consumption (MWh) by MRT	Available in some cases but not always	Assumed from literature survey
Land use impact of BRT/MRT systems	No	Assumed from literature survey
BRT system component information - running ways, stations, vehicles, service patterns, ITS application, BRT branding	Yes	

ADB = Asian Development Bank, BRT = bus rapid transit, g = gram, ITS = Intelligent Transportation System, km = kilometer, MRT = metro rail transit, MWh = megawatt-hour, NO_x = nitrogen oxide, RRP = report and recommendation of the President, PCR = project completion report, SARD = South Asia Department, TEEMP = transport emissions evaluation model for projects.
Source: Independent Evaluation Department.

CARBON EMISSIONS ANALYSIS OF SELECT PROJECT CASES

A. Ever Increasing Traffic Growth cannot be Expected without Road Improvements

1. Many Asian Development Bank (ADB) transport project analyses continue to assume that traffic will grow following general trends into the foreseeable future regardless of transportation policies and investments. This has been characterized as "predict-and-provide planning."[1] This assumption undermines the integrity of both economic and environmental analysis of transportation projects. In moving to evaluate the greenhouse gas (GHG) impacts of transportation investments, ADB needs to reexamine the acceptability of this methodological approach, which has been increasingly criticized in global transport policy.[2] ADB needs to adopt good practice approaches that recognize that traffic grows to fill the space allotted to it and similarly traffic growth slows in the face of less ample provision of road space, traffic policies designed to slow and calm traffic, and higher road user and parking charges.[3]

2. This evaluation knowledge brief has built on good practice approaches by recognizing that emissions from roads carrying a high intensity of traffic are highly sensitive to the saturation limits of volume to capacity (V–C) ratios. It is incorrect to assume that roads can always accommodate increasing traffic volume without increases in capacity. Many corridors show some kind of saturation after the V–C ratio exceeds 1.0 as an increasing number of travelers change their destination choice, mode of travel, route, or time of day of travel, or decide not to travel at all.

3. To capture this impact on emissions in the transport emissions evaluation model for projects (TEEMP), corridors were tested under varying conditions of V–C ratios (1.5, 2.0, 2.5, and 3.0). Low traffic volume rural roads do not show any influence of this saturation as the V–C ratio rarely exceeds 1. However, as Figure 11 of the main text shows, high volume roads show significant carbon dioxide (CO_2) emission impacts if traffic saturation ceilings are assumed.

4. Economic and environmental analysts need to make assumptions about the maximum corridor saturation factor, as this can significantly change the forecast for future CO_2 emissions and user benefits. While peak-spreading can enable V–C ratios as high as 2, it is unrealistic to assume that most corridors will sustain V–C ratios exceeding 2 on a routine basis, as travelers decide not to travel, to switch modes, or to choose other destinations to avoid excessive congestion delays.

B. Road Capacity Expansion Produces Complex Time-Dependent Effects

5. Proponents of the "predict-provide" planning transportation paradigm for decades relied on a simple logic that assumed that providing additional road capacity would automatically reduce congestion, increase traffic speeds, and reduce air pollution and fuel use. More recent research has shown that this simple framework is often not borne out, given the more complex system interaction effects seen in real world transportation and behavioral systems.

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[1] Culture Change. *Predict and Provide Planning is a Dead End*. http://culturechange.org/issue8/predict%20and%20provide.htm (accessed 27 May 2010).

[2] S. Owens. 1995. "From 'predict and provide' to 'predict and prevent'?: Pricing and planning in transport policy." *Transport Policy*. 2 (1) January. pp. 43–49.

[3] For a bibliography of sources on this topic, see http://www.moderntransit.org/links-induced.html. For a fuller discussion of a methodology to integrate consideration of induced traffic in user benefit estimation, see extensive work by the University of Leeds for the World Bank—P. Mackie, J. Nellthorp, and J. Laird. 2003. Treatment of Induced Traffic. *Toolkit for the Economic Evaluation of World Bank Transport Projects*. Institute for Transport Studies, University of Leeds. http://www.its.leeds.ac.uk/projects/WBToolkit/Note6.htm

6. In some cases, increasing road capacity will reduce congestion and increase traffic speeds from very low levels, thereby reducing the emission rate per kilometer (km) of motor vehicle travel, at least in the short term. This can lead to significant CO_2 emission reduction. However, the higher traffic speeds brought about by increased capacity do not always reduce CO_2 emissions, even in the near term.

7. This is evident from the application of the TEEMP to several ADB road projects, looking only at near-term impacts on CO_2 emissions. Table A5.1 shows the impact of capacity expansion on five corridors during the first 5 years after an improvement, excluding induced traffic effects. CO_2 emissions decrease with the project in only two of the five cases; they increase by a modest amount in three cases. When new road capacity promotes traffic speeds higher than 70 kilometers per hour (kph) from a business-as-usual speed of 45 kph–70 kph, this may boost even short-term CO_2 emissions (Table A5.1).

Table A5.1: Impact of Road Capacity Expansion in Corridors during 5 Years
(excluding induced traffic impact)

Project	Scenario	**Description** (kilotons CO_2 per km) 1st Year	2nd Year	3rd Year	4th Year	5th Year	~V–C	Average Speed (kph)
Belgaum–Dharwad	Business as usual	2.65	2.78	2.92	3.07	3.22	0.45	58
	After project	2.69	2.83	2.97	3.12	3.27	0.20	80
Salem–Namakkal	Business as usual	2.28	2.39	2.51	2.63	2.77	0.40	59
	After project	2.32	2.43	2.55	2.67	2.81	0.20	80
Surat–Manor	Business as usual	5.96	6.45	7.43	7.96	8.11	0.85	41
	After project	5.42	5.84	6.33	6.66	7.21	0.40	76
Ho Chi Minh–Long	Business as usual	3.10	3.35	3.63	3.94	4.27	0.52	57
Thanh–Dau Giay	After project	3.21	3.48	3.76	4.07	4.41	0.23	80
Almaty–Kaskelen	Business as usual	0.56	0.60	0.63	0.67	0.71	0.34	37
	After project	0.49	0.52	0.55	0.59	0.62	0.22	57

CO_2 = carbon dioxide, km = kilometer, kph = kilometer per hour.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports from the National Highway Authority of India.

8. Expanding high-speed road capacity is more likely to increase CO_2 emissions, even in the short term, while expanding moderate traffic speed road capacity is less likely to increase short-term CO_2 emissions and may help cut emissions in the short run.

C. Road Maintenance can Significantly Affect Vehicle Carbon Dioxide Emission Rates

9. Road maintenance improvement projects can significantly affect vehicle emissions. Many ADB projects include surface and roughness improvement elements, which reduce road users costs, discomfort, pollution, and travel time delays. Road roughness is an expression of surface irregularity, and affects ride quality and fuel consumption. Table A5.2 captures the impact of roughness on fuel consumption. Roughness is measured in units of meters of deviation from a flat surface per km.

Table A5.2: Impact of Road Roughness on Fuel Consumption[a]

Roughness (m/km)	**Impact on Fuel Consumption**
2	1.00
3	0.99
4	0.98
5	0.98
6	0.97
7	0.96
8	0.95
9	0.95
10	0.94
11	0.93
12	0.92
13	0.92
14	0.91
15	0.90

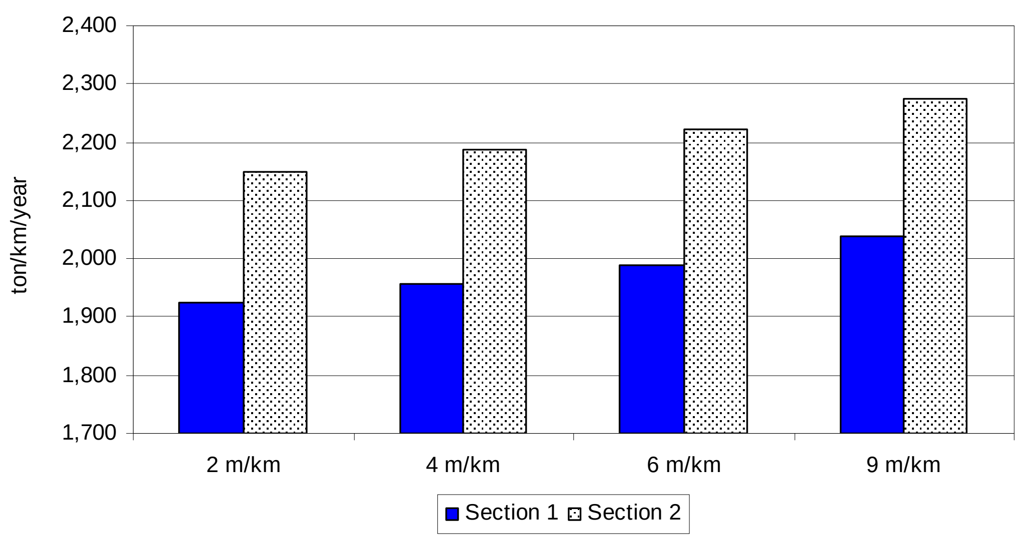
km = kilometer, m = meter.

[a] Multiplication factor for fuel consumption (kilometer per hour). It shows decrease in fuel efficiency with increasing roughness.

Source: Asian Development Bank. 2009. *Green Transport – Resource Optimization in the Road Sector in the People's Republic of China*. Manila.

10. To illustrate the impact of roughness on emissions, various scenarios were modeled for two sections of a typical access-controlled highway in India (Salem–Namakkal) and the impact of roughness was isolated. When the roughness was increased from 2 meters (m) per km to 4 m/km, emissions (CO_2 tons/km/year) increased by 1.6%; with roughness of 6 m/km, emissions increased by 3.3%; and with roughness of 9 m/km, emissions increased by 5.8% (Figure A5.1).

Figure A5.1: Impact of Road Roughness on Carbon Dioxide Emissions for Two Sections of Controlled Access Highway in India



km = kilometer, m = meter.

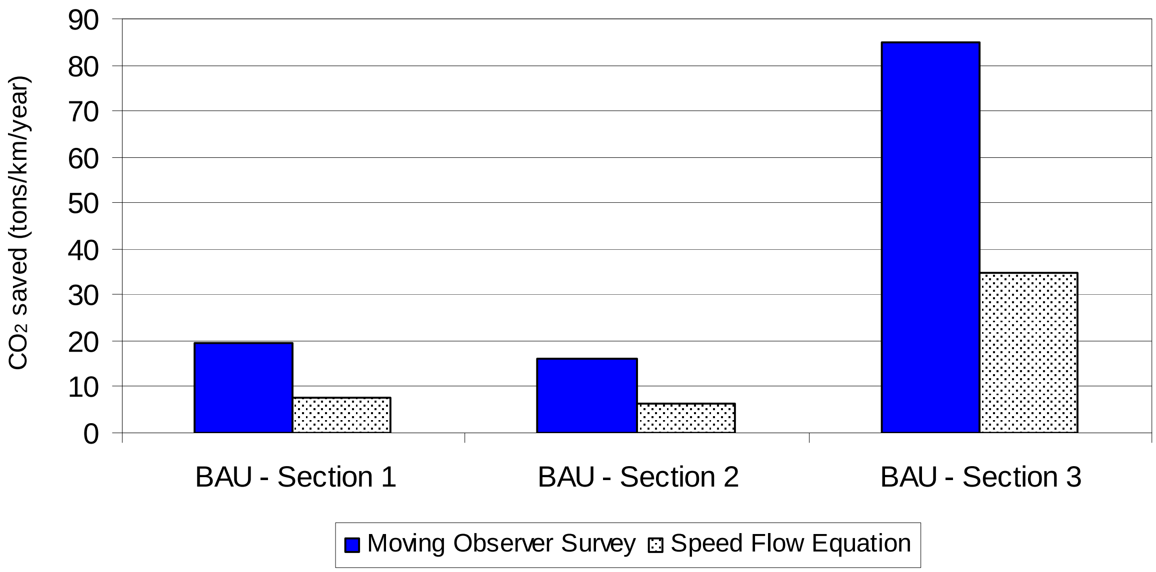
Source: Independent Evaluation Department estimate based on review of National Highway Authority of India project documents and reports for Salem–Namakkal highway.

11. Roughness also indirectly affects fuel consumption by altering vehicle travel speeds. However, models currently used for project appraisal (whether for expressways, rural roads, or urban roads) mostly rely on the V–C ratio to estimate traffic speeds, disregarding the impact of

roughness on speed. A proper evaluation of CO_2 emissions and other speed-dependent parameters needs to consider how roughness can indirectly affect CO_2 by affecting traffic speeds.

12. This is illustrated in estimating CO_2 for a road rehabilitation project in the Lao People's Democratic Republic (Figure A5.2).[4] Because of the very poor existing pavement quality on this two-lane road, drivers can travel at no more than 8 kph–15 kph. Traffic levels are low, producing an existing V–C ratio of 0.02 to 0.10. Traffic speed-flow equations (based only on the V–C ratio) estimate traffic speeds of 30 kph, or two to four times greater than the actual speeds in the business-as-usual case. The use of such a speed for CO_2 emission analysis underestimates the business-as-usual CO_2 emissions by nearly two-thirds, and underestimates the CO_2 reductions produced by road rehabilitation and sound ongoing maintenance.

Figure A5.2: Carbon Dioxide Emissions
Impact of Speed Estimated by Moving Observer Survey versus Speed Flow Equations



BAU = business as usual, CO_2 = carbon dioxide, km = kilometer, Lao PDR = Lao People's Democratic Republic.
Source: Independent Evaluation Department estimate based on review of Asian Development Bank project documents and reports; and Asian Development Bank. 2009. *Performance Evaluation Report: Rural Access Roads Project for the Lao People's Democratic Republic*. Manila.

13. With a sound baseline speed estimate, speeds can be forecast not only from V–C ratios, but also from projected changes in roughness over the lifetime of the project, based on maintenance plans or standards for the facility. Sound baseline speed and related travel time estimates are also important to the integrity of user benefit estimates.

14. Road roughness needs to be accounted for in CO_2 analysis. It is advisable to measure the actual traffic speeds in travel corridors for both rural and urban projects to help ensure the integrity of project economic and environmental impact appraisals. Moving observer or floating car surveys need to be collected whenever possible to validate and support project environmental appraisal, including CO_2 analysis.

[4] ADB. 2009. *Performance Evaluation Report: Rural Access Roads Project for the Lao People's Democratic Republic*. Manila. Contracts C1, C2, and C3 have been considered in this project analysis.

D. Public Transport Projects have a High Carbon Dioxide Emission Reduction Potential, with Similar Impacts for Metro Rail Transit and Bus Rapid Transit System Projects

1. Key Factors by which Public Transport Cuts Carbon Dioxide Emissions

15. Because public transportation offers the potential to carry relatively more passengers in a single high efficiency vehicle, CO_2 per passenger-km tends to be lower than for private motor vehicles, as long as the occupancy of public transport vehicles is high. Public transport investment also offers potential to anchor higher density mixed-use development, where a larger share of trips can be made over short distances on foot or by bicycle. Public transportation investment reduces GHG emissions when it cuts average trip lengths (avoiding unnecessary travel); spurs more walking, cycling, and high efficiency public transport use (shifting trips to low carbon modes); and supports greater amounts of urban development in GHG efficient forms (with buildings that support higher heating, cooling, and energy efficiency). The TEEMP accounts only for the transportation aspects of public transport GHG emissions impacts, not building impacts.

16. A new bus rapid transit (BRT) has the potential to reduce CO_2 by many different means, including

- (i) reducing vehicle-km by buses and other motor vehicles;
- (ii) causing some vehicles to switch to lower carbon fuel/more efficient buses;
- (iii) causing mode switching from higher to lower carbon modes;
- (iv) causing higher vehicle speeds that cut GHG/passenger-km for buses and other traffic;
- (v) boosting the passenger per bus load factor; and
- (vi) spurring more transit-oriented, walkable land development.

2. Evaluating Public Transport Investments with TEEMP

17. Described in its most basic terms, the TEEMP takes as an input or calculates the projected number of passengers on a proposed BRT or metro rail transit (MRT) system, estimates the CO_2 emissions of the new system, and compares the CO_2 these passenger trips would have generated if they were still using their old modes to make the same trip.

18. A key assumption is the estimate of what share of trips using a proposed new BRT or MRT will have been drawn from other competing modes of travel, and the CO_2 emission characteristics of those former modes of travel. The degree to which a BRT or MRT will compete successfully against other modes is a function of the characteristics of the public transport service offered, such as speed and convenience. The TEEMP also evaluates the CO_2 emissions of the BRT or MRT service based on such factors as fuel used, vehicle occupancy, and speed. The model is sensitive to the composition of the vehicle fleet in use in a corridor and the markets from which public transport passengers for new services are drawn, as well as the efficiency of the new public transport services. A major factor is also whether the BRT or MRT trips substitute for vehicle trips used as the prior mode of travel, or whether the new BRT or MRT trips are additive to the prior travel.

19. The BRT TEEMP captures many of these effects by using system characteristics and speed factor scores based on the BRT system attributes. These weights are based on best practice in BRT system planning worldwide and are shown in Table A3.9 in Appendix 3. They can be used to help evaluate the degree to which a system is likely to attract significant mode share diversion from competing modes. They can also be used to evaluate the likely BRT

system speed, an important factor in estimating both bus emissions and competitiveness with competing modes. A poorly designed BRT system with only a minority of the best practice score elements can be compared in the TEEMP with a high scoring BRT system that includes most of the system elements listed in Table A3.9. Incomplete BRT systems (with a low score) are likely to reduce CO_2 only modestly, while complete systems (score over 85) have the potential to generate emissions reductions comparable to MRT. This same approach to evaluating key project characteristics likely to determine the effectiveness of a transport project intervention in reducing CO_2 will be further developed for other modes as the TEEMP evolves.

20. To demonstrate its use in evaluating the impact of public transport projects, the TEEMP was used to analyze MRT and BRT system projects. Using the same baseline data from two metro projects—Metro Manila Light Rail Transit (LRT) 1 (North Extension) and Bangalore Metro— emissions saved over 20 years were quantified under various degrees of modal shift for both the improvement scenarios. The quantification encompasses construction, operation, and savings achieved from the business-as-usual scenario.

21. For each of these two MRT projects, hypothetical alternative BRT projects were defined accommodating the same traffic in the same corridors. A comparison of these two scenarios shows that there would be little significant change between BRT and MRT from an emissions perspective. Both projects led to very high annual average emission savings. A BRT alternative would cost less money and take less time to implement, but would require more displacement of surface street space now allocated to private motor vehicle traffic, which might entail a higher short-term political cost.

22. A BRT system analysis was conducted to examine sensitivity to four different scenario elements, using the initial BRT TEEMP:

(i) complete and incomplete BRT system;
(ii) future constant trip mode share and motorized scenario;
(iii) with and without induced land use benefit factor; and
(iv) various degrees of motorized shift—100%, 80%, 50%, 20%, mode shift factor, shifting from only intermediate public transport and public transport.

23. An MRT analysis was conducted to examine sensitivity to four different scenario elements:

(i) high emission scenario (assuming grams per kilometer [g/km] value of 80);
(ii) low emission scenario (assuming g/km value of 25 [Manila] and 20 [Bangalore]);
(iii) with and without induced land use benefit factor; and
(iv) various degrees of motorized shift—100%, 80%, 50%, 20%, mode shift factor, shifting from only intermediate public transport and public transport.

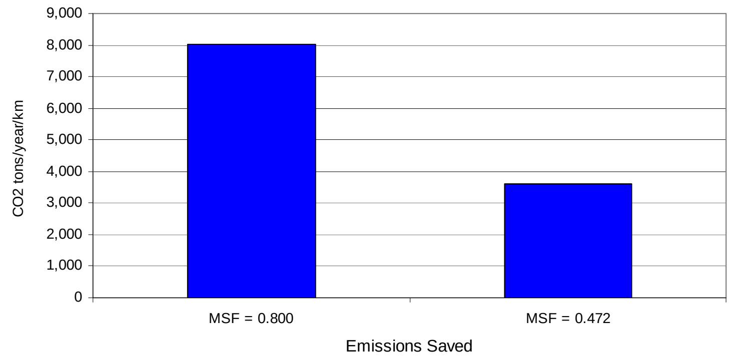
3. Public Transport need to be well Designed to be Effective in Cutting Carbon Dioxide Emissions

24. If public transport projects fail to provide a good level of service that can offer attractive travel speed and reliability, it will fail to arrest or reverse the decline of public transport use in cities undergoing rapid motorization and may produce few or even negative CO_2 benefits. The same public transport investment can generate far higher CO_2 reduction if improved public transport is supported by travel demand management, such as parking or road use pricing and improved conditions for walking and cycling.

25. This is illustrated in Figure A5.3, which shows the CO_2 reduction produced by Bangalore Metro under two different scenarios—one with strong travel demand management measures

(labeled mode shift factor [MSF] = 0.8) and the other without such measures (labeled MSF = 0.472). These scenarios reflect the effects of shifting 47.2% vs. 80%, respectively, of motorized trips in the metro corridor to Bangalore Metro. Where there is an increase in mode shift from 47.2% to 80%, the CO_2 emissions savings increase by 123%.

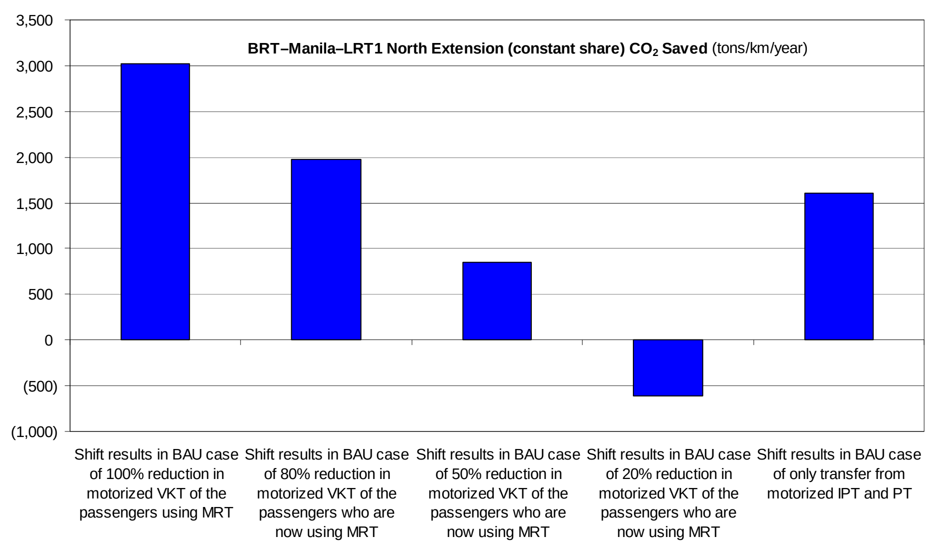
Figure A5.3: Mode Shift Factor Impact on Carbon Dioxide Emissions



CO_2 = carbon dioxide, km = kilometer, MSF = mode shift factor.
Source: Independent Evaluation Department analysis based on data from Bangalore Metro project, which is under construction by Bangalore Metro Rail Corporation. http://bmrc.co.in (accessed 14 May 2010).

26. This is similarly illustrated for a BRT scenario in the Manila LRT 1 corridor (Figure A5.4). If the BRT were not well supported by travel demand management and so poorly implemented that it captured only 20% of the motorized vehicle kilometer of travel (VKT) in the corridor, it would lead to higher CO_2 emissions.

Figure A5.4: Impacts of Modal Shift on the Carbon Dioxide Emissions Savings

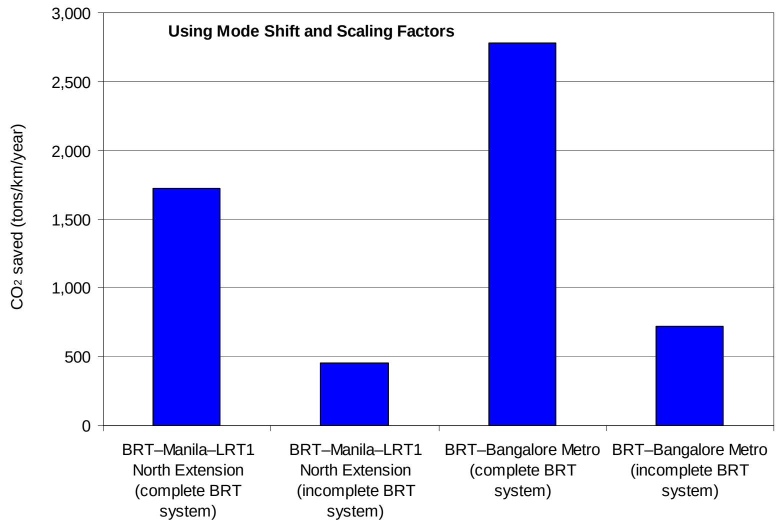


BAU = business as usual, BRT = bus rapid transit, CO_2 = carbon dioxide, IPT = intermediate public transport, km = kilometer, LRT = light rail transit, MRT = metro rail transit, PT = public transport, VKT = vehicle kilometer of travel.
Source: Independent Evaluation Department analysis based on data from Metro Manila.

27. A poorly designed BRT system with only a minority of the best practice score elements can be compared in the TEEMP with a high scoring BRT system that includes most of the system elements listed in Table A3.9 in Appendix 3. Incomplete “BRT-light” systems are found

to minimally reduce CO_2, while complete systems have the potential to generate large emissions reductions in the two corridors examined (Figure A5.5).

Figure A5.5: Carbon Dioxide Emission Savings Comparison between a Complete and Incomplete Bus Rapid Transit System



BRT = bus rapid transit, CO_2 = carbon dioxide, km = kilometer, LRT = light rail transit.
Source: Independent Evaluation Department estimates based on data from Bangalore and Metro Manila projects.

28. Another case study was examined using the BRT TEEMP to evaluate the 23 km Guangzhou BRT system that opened in February 2010. The analysis compared the BRT scenario to a no-action scenario for three time horizons (2010, 2019, and 2029) and calculated a 20-year total.[5] The results are shown in Table A5.3. This analysis shows construction emissions of 1,101 tons of CO_2 per km of BRT system, consistent with emissions estimated for other systems. It shows that this project is likely to reduce 61,222 tons of CO_2 per km of BRT system over its 20-year lifetime.

Table A5.3: Estimated Carbon Dioxide Emission Impact of Guangzhou Bus Rapid Transit Phase I System

Tons of CO_2 change caused by Guangzhou Phase I Bus Rapid Transit	**2010**	**2019**	**2029**	**20-Year Total**
New bus rapid transit system emissions	2,822	3,078	3,530	62,867
Emissions removed from former buses	(15,679)	(20,200)	(25,507)	(409,240)
Emissions removed from modal shift	(2,078)	(3,399)	(7,168)	(84,300)
Emissions removed by more efficient traffic and bus operations	(15,565)	(20,520)	(29,163)	(434,987)
Construction emissions	25,312	0	0	25,312
Land use impact emission reduction	0	(29,754)	(55,410)	(567,760)
Total Direct Emissions	**(5,188)**	**(70,795)**	**(113,718)**	**(1,408,108)**

( ) = negative number, CO_2 = carbon dioxide.
Source: Data sourced from Guangzhou project by Institute of Transportation and Development Policy.

29. This TEEMP application made use of ridership estimates for the existing public transport services in the corridor to help derive an estimate of BRT system ridership based on which existing routes share a significant portion of their routes with the BRT facilities that were to be

5 This 20-year analysis does not include maintenance of infrastructure emissions following construction.

developed. This BRT model offers a refined methodology for estimating BRT ridership demand. It demonstrates its capability to distinguish between emission reductions caused by mode shifting; improved operational speeds; replacement of inefficient, lower vehicle occupancy buses with higher efficiency, higher vehicle occupancy buses; and land use.

30. The degree to which new high capacity public transport services displace rather than augment existing motor vehicle use (whether public or private vehicles) makes a significant difference in the CO_2 reductions produced by that public transport investment. For maximum CO_2 benefits, it is desirable for new public transport services to shift travel from less efficient modes and vehicles to more efficient vehicles and modes of travel. This can be maximized when the new public transport investment also involves scrapping old, inefficient vehicles (rather than merely exporting them for reuse elsewhere) or reducing their continued use through measures such as road space reallocation or road pricing. Ridership and CO_2 reductions can be maximized by ensuring high public transport speeds and reliability, following good practice standards for system design and operations.

4. Static vs. Dynamic Baseline for Carbon Dioxide Emission Modeling

31. The assertion that "energy savings from a modal shift is constant over time"[6] is based on the assumption that there is a constant mode share in a city or corridor over the time frame of analysis. However, the trend in most developing country cities in recent years is that mode shares for public transport, walking, and cycling are falling in the face of rapidly increasing motorization.[7]

32. This has led to the use of dynamic baselines to evaluate transportation GHG emissions. Rather than assuming a fixed backdrop for implementation over time in the business-as-usual do-nothing case, the analysis compares an action scenario vs. a business-as-usual case in which recent trends of modal change and traffic growth continue unabated.

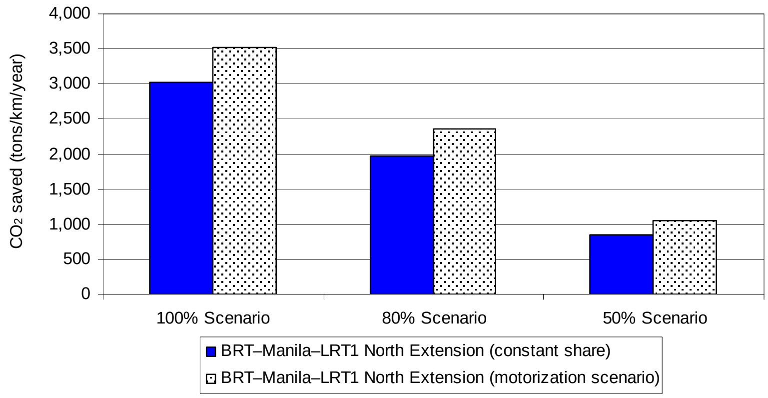
33. To illustrate this approach, the TEEMP was used to evaluate a hypothetical BRT project in the Manila North Extension LRT 1 corridor compared with both a "constant share" baseline and a "motorization scenario." In the latter case, the assumed no-action baseline future level of motorization is faster and is assumed to cause the overall public transport mode share to fall to 35% by the end of the 20-year project life in the motorization scenario.[8] In the former "constant share" case, the overall public transport mode share is held at a particular percent over that project life. This change from a static to a dynamic baseline increases the estimated CO_2 emission reductions caused by the project by 13%–24% (Figure A5.6).

[6] O. Grandvoinet and C. Bernadac. 2009. *Carbon Footprint Methodologies for Development Projects and Case Studies*. Agence Française de Développement.

[7] Intergovernmental Panel on Climate Change. 20007. Working Group III: Mitigation of Climate Change. 5.3.1.5 Road Transport: Mode Shifts. *IPPC Fourth Assessment Report, Climate Change 2007*. Geneva.

[8] This value can be considered conservative as many cities show a current public transport trip mode share of less than 40%.

Figure A5.6: Carbon Dioxide Emissions Impact of Future Motorization (trip share)



BRT = bus rapid transit, CO_2 = carbon dioxide, km = kilometer, LRT = light rail transit.
Source: Independent Evaluation Department analysis based on data from Metro Manila Project.

34. Given the very dynamic changes in motorization, traffic, and modal shares across most Asian cities, it is important to consider dynamic baseline scenarios in CO_2 impact analysis for projects. However, dynamic baselines derived from recent trends should not be taken rigidly, but need to be adopted as reference frameworks that can be modified by changes in policies, investments, planning frameworks, and pricing. Sensitivity analysis is warranted where there is significant uncertainty about projection of transportation and development trends. The ways that transport CO_2 project appraisals can inform the development of regional low-carbon growth plans should also be considered.

5. Smart Traffic Management and Induced Traffic Impacts of Major Urban Transport Investment Programs can have Significant Effects on Carbon Dioxide Emissions

35. Major public transport investments often bring along traffic reductions on their own or through complementary smart traffic management or pricing measures that can boost speed of other traffic in the public transport corridor. These can include measures such as

- (i) designing BRT systems so that they remove significant existing traffic congestion from corridors and benefit existing traffic flows;
- (ii) designing BRT platforms so that buses and cross traffic at intersections do not impede each other;
- (iii) installing computerized and coordinated traffic signal systems;
- (iv) implementing real-time traffic operations management;
- (v) travel demand management including parking pricing, street space reallocation, company car management, auto use restrictions; and
- (vi) road user charging.

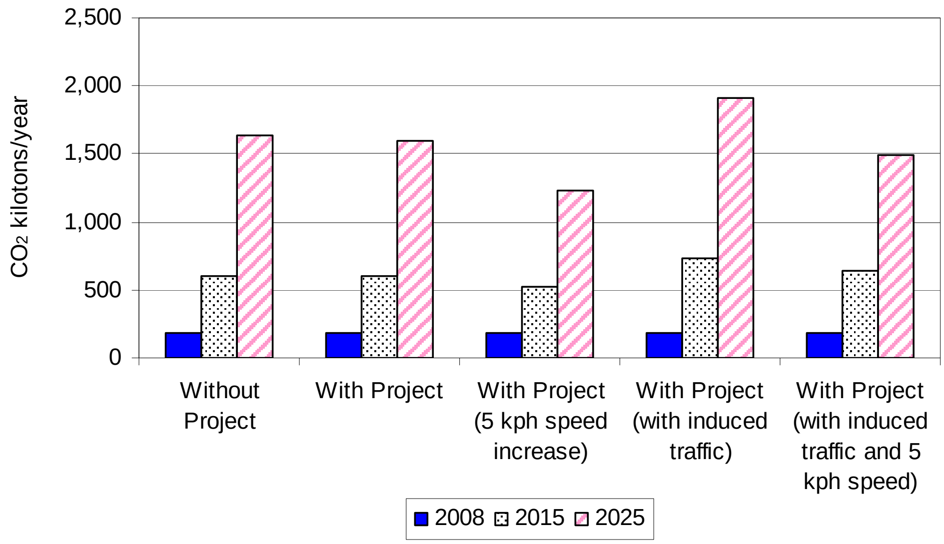
36. These traffic reductions may be offset by the impact of urban road capacity expansion, which induces new traffic. To illustrate the effects of such interacting changes using the TEEMP, several scenarios were evaluated for the Lanzhou Sustainable Urban Transport Project. This project comprises construction of 33.8 km of urban roads, including BRT facilities and nonmotorized transport lanes. A baseline survey for the project is currently being updated and the data available is limited. However, using the available data from a four-step traffic model and hypothetical scenarios, the impacts of a BRT system on the city in the context of these other changes was evaluated.

37. The traffic model reflects a high intensity of trip reorganization in the city related to the improvements; these are reflected in the TEEMP through the data input for each scenario. Assuming average traffic speeds of 30 kph in 2008, 25 kph in 2015, and 20 kph in 2025, CO_2 emissions were quantified for five scenarios:

(i) without the project: no build (business as usual);
(ii) with the project case, assuming neither induced land use impacts from BRT nor any increase in traffic speeds;
(iii) with the project case, assuming no induced land use impacts from BRT, but with an increase in the average speed by 5 kph;
(iv) with the project case, with induced land use impacts from BRT and no increase in average traffic speeds; and
(v) with the project case, with both induced land use impacts of BRT and a 5 kph increase in traffic speeds.

38. The results of this analysis for Langzhou are shown in Figure A5.7. This shows that if there is no improvement in traffic speed as a result of the package of measures, and if induced traffic impacts are not considered, there is a reduction in emissions. This reduction can be maximized if measures such as the ones noted above are taken as part of the project to improve average traffic speeds.

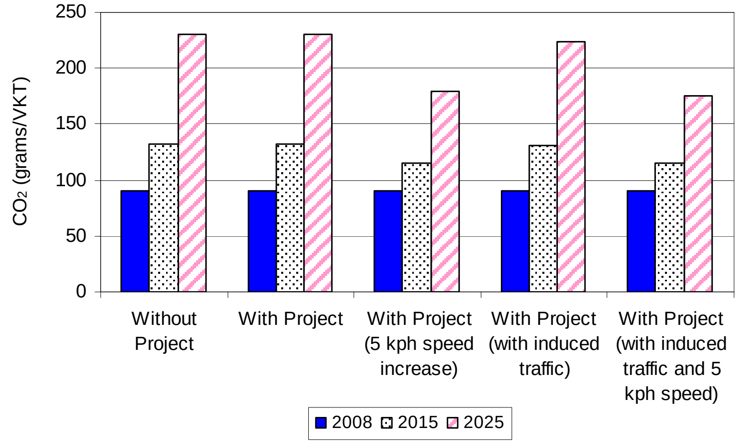
Figure A5.7: Carbon Dioxide Impacts of a Bus Rapid Transit System on the City
(Lanzhou Sustainable Urban Transport Project)



CO_2 = carbon dioxide.
Source: Independent Evaluation Department estimates based on data in Asian Development Bank reports and recommendations of the President and project completion reports.

39. If induced traffic is considered and there is no improvement in speed, emissions would increase. However, the travel becomes more carbon efficient (Figure A5.8). With improvement in speed and incorporating induced development traffic in project evaluation shows huge reduction in emissions and improvement in efficiency.

Figure A5.8: Impact on Carbon Dioxide Emissions Intensity of Travel



CO_2 = carbon dioxide, kph = kilometer per hour, VKT = vehicle kilometer of travel.
Source: Independent Evaluation Department estimates based on data in Asian Development Bank reports and recommendations of the President for Lanzhou Sustainable Urban Transport Project (Loan 2601).

40. Integrated urban transport initiatives offer ADB many opportunities to reduce the carbon footprint of transport lending. By combining multiple measures that reinforce each other to expand and enhance the attractiveness of low carbon sustainable travel choices, it is possible to produce considerable reductions in transport-related CO_2 while enhancing mobility, economic development, and equity of access to opportunities for low and moderate income individuals. The key to success in such measures is to eliminate both visible and hidden subsidies for driving, expand high efficiency public transport services such as BRT, improve the quality of the walking and cycling environment, and encourage more efficient spatial planning and land development patterns.

E. Freight Rail is More Energy Efficient than Road-Based Freight Transport

41. The core market for rail freight services is the haulage of heavy bulk commodities. There has been a general tendency for shippers to prefer the use of trucks and air freight for higher value container-based cargo since those modes have higher average speeds and greater reliability. Although rail- or water-based freight transport may be more efficient, they serve far fewer destinations than truck-based transport. For many types of shipments, intermodal freight services, involving some combination of modes, may be a necessary or more CO_2 efficient option.

42. When ADB or another entity finances the addition or improvement of rail services in a corridor or improved intermodal exchange facilities between truck and rail, it may spur a diversion of some freight traffic in that corridor from truck to rail, reducing CO_2 operational emissions. When ADB or another entity finances improvement of high-speed highways in a corridor, it may spur a diversion of some freight traffic in that corridor from rail to truck, increasing CO_2 operational emissions. Such investments can also influence decisions about locating the new manufacturing production facilities or distribution centers, which can, in turn, lock in for decades to come lower or higher CO_2 emission choices and opportunities.

43. The TEEMP was framed to allow users to do a quick comparison of highway vs. railway emissions for the same corridor. The analysis depends on selecting appropriate emission factors depending on railway fuel consumption. Based on literature review from global studies, high and

low values of emission factors were adopted for railways depending on technology and efficiency. To make the analysis more comprehensive, energy intensity parameters for railways from an ADB project were established as suggested median values.[9] High scenario refers to emission factor equivalent to 130 g per passenger-km. Low scenario refers to emission factor equivalent to 45 g per passenger-km. These are based on research on emission factors of railways.

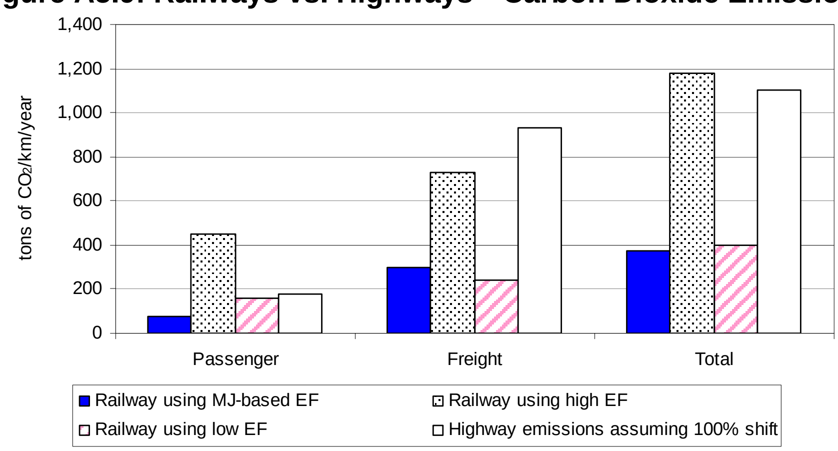
44. Analysis performed on the Hefei–Xi'an Railway Project indicates that the CO_2 emissions may range from 377 tons of CO_2 per km per year to 1,180 tons of CO_2 per km per year. To investigate the likely emissions from alternate highways, the same traffic data was used, with default average emission factors for passenger and freight based on a typical partial access controlled highway. The results (Figure A5.9), suggest that if future efficiency improvements in both highways and railways are disregarded,[10] the following conclusions may be drawn:

(i) For passenger transport, CO_2 emissions from highways exceed emissions from railways for the low emissions factor scenario and when energy intensity values from the PRC are adopted. However, when the high emissions factor scenario is considered for railways, highways are more efficient for passenger transport.

(ii) Under three scenarios examined, shifting freight to road-based truck transport from rail would produce emissions at least 25% higher; in two of the scenarios, truck emissions would be 210%–283% higher.

(iii) If 100% of the currently projected rail passenger and rail freight traffic in this corridor were shifted to road-based modes, the TEEMP estimates that the CO_2 operations emissions would rise by 193% or by 728 tons/km/year.

Figure A5.9: Railways vs. Highways—Carbon Dioxide Emissions



CO_2 = carbon dioxide, km = kilometer, MJ = megajoule, EF=emissions factor, high EF= emission factor equivalent to 130 grams per passenger-km, Low EF= emission factor equivalent to 45 grams per passenger-km.
Source: Independent Evaluation Department analysis based on empirical research.

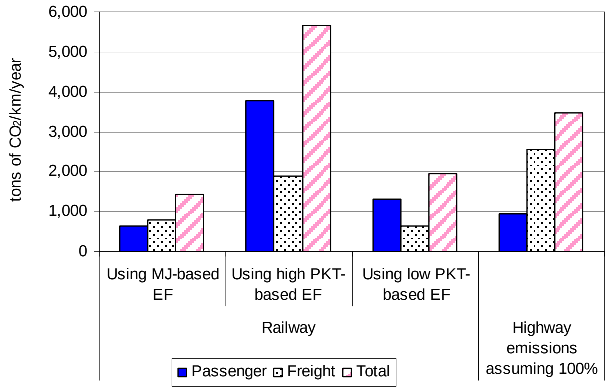
45. Passenger and freight demand from two road corridors in India and Viet Nam were also examined. The analysis (Figure A5.10) shows that if the highway project were replaced by a railway, which carried 100% of the traffic that had been carried by the highway, CO_2 emissions would rise by 144% for the Indian highway (2,060 tons/km/year) and 138% for the Vietnamese highway (3,779 tons/km/year). Further analysis with more accurate loading inputs, and including

[9] The International Energy Agency Sustainable Mobility Project model uses 0.3 megajoules (MJ) per passenger-km and 0.24 MJ per ton-km freight for 2005. The ADB technical assistance Lanzhou–Chongqing Railway Project uses an energy intensity of rail of 0.3 MJ per km and for road passenger transport uses 0.39 MJ per km. Document located at http://www.adb.org/Documents/Reports/ Consultant/35354-PRC/35354-PRC-TACR.pdf.

[10] Research indicates that the model efficiency improvements can play an important role in both highways and railways. Modal efficiency improvements include fuel economy and occupancy/loading improvements.

construction aspects, could refine the methodology and offer better insights. It is implausible that a railway could replace 100% of the highway's travel function.

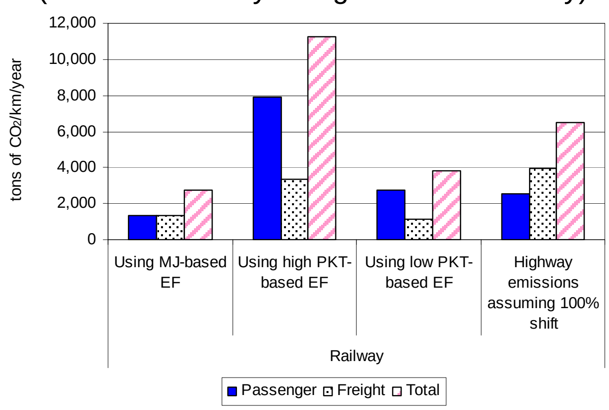
Figure A5.10: Railways vs. Highways—Carbon Dioxide Emissions
(Salem Namakkal National Highway 7, India)



CO_2 = carbon dioxide, km = kilometer, NH = national highway, MJ = megajoule, EF = emission factor, high EF = emission factor equivalent to 130 grams per passenger-km, low EF = emission factor equivalent to 45 grams per passenger-km, PKT = passenger-km traveled.
Source: Independent Evaluation Department estimates based on data collected from Salem Namakkal Road Project, National Highway Authority of India.

46. Proposals for new or expanded highways aimed at serving improved goods movement in a corridor need to be subject to alternative analysis that considers whether investment in new or improved railway, waterway, or intermodal freight systems might provide effective complementary or alternative capacity to address the same needs with a smaller carbon footprint. Figure A5.11 gives an example of such comparison. Proposals for new or expanded highways aimed at serving improved passenger movement in a corridor could be subject to alternative analysis that considers whether investment in new or improved public transport services, including better bus or rail services, might provide effective complementary or alternative capacity to address the same needs with a smaller carbon footprint.

Figure A5.11: Railways vs. Highways—Carbon Dioxide Emissions
(Ho Chi Minh City–Long Thanh–Dau Giay)



CO_2 = carbon dioxide, km = kilometer, MJ = megajoule, EF = emission factor, high EF = emission factor equivalent to 130 grams per passenger-km, low EF = emission factor equivalent to 45 grams per passenger-km, PKT = passenger km traveled.
Source: Independent Evaluation Department estimates based on data in Asian Development Bank reports and recommendations of the President and project completion reports.

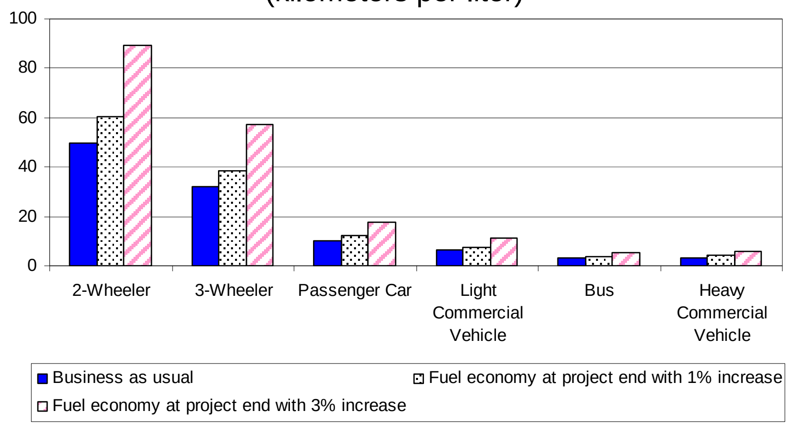
IMPACT OF TECHNOLOGICAL IMPROVEMENTS ON TRANSPORT PROJECT CARBON FOOTPRINT

1. Technological improvement offers a solution in reducing carbon emissions. To investigate the impact of technological improvements on project carbon emissions, some alternate hypothetical cases were quantified. The scenarios considered are described below.

A. Increase in Fuel Economy

2. To quantify the impact of increasing fuel economy on project carbon emissions, the overall fleet fuel efficiency of vehicles was increased annually by 1% and 3%. Currently, only a handful of countries (People's Republic of China, India, Singapore, Thailand, etc.) are planning and executing fuel economy measures, and it takes several years to show the impact of new fuel economy standards as the rate of vehicle fleet turnover is typically about a decade or longer, except where the base of vehicle ownership is very small and motorization is rapid. With an annual increase in fuel economy of 1% and 3%, emissions were quantified on a national highway project located in India. Figure A6.1 indicates the impact on fuel consumption of vehicles.

Figure A6.1: Fuel Economy for Various Vehicle Types After 20 Years
(kilometers per liter)



Source: Independent Evaluation Department analysis based on data from various sources.

3. The impact of technology on a project life cycle of 20 years is significant. The decrease amounts to 11% and 29% from without change in technology scenario (i.e., with and without improvement refers to with and without fuel economy improvement). But to achieve that kind of reductions, the fuel consumption of vehicles in kilometer (km) per liter needs to be made efficient by 21% and 78%, which needs proactive financing, policy, and fast implementation. This is a challenge for the policy makers.[1]

B. Eco-Driving

4. Eco-driving involves changing the driving pattern to reduce fuel consumption and accidents. Many studies indicate that the impact can range from 5% to 20%.[2] Researchers have found that there are rebound effects of eco-driving, and the intensity of impacts reduces with

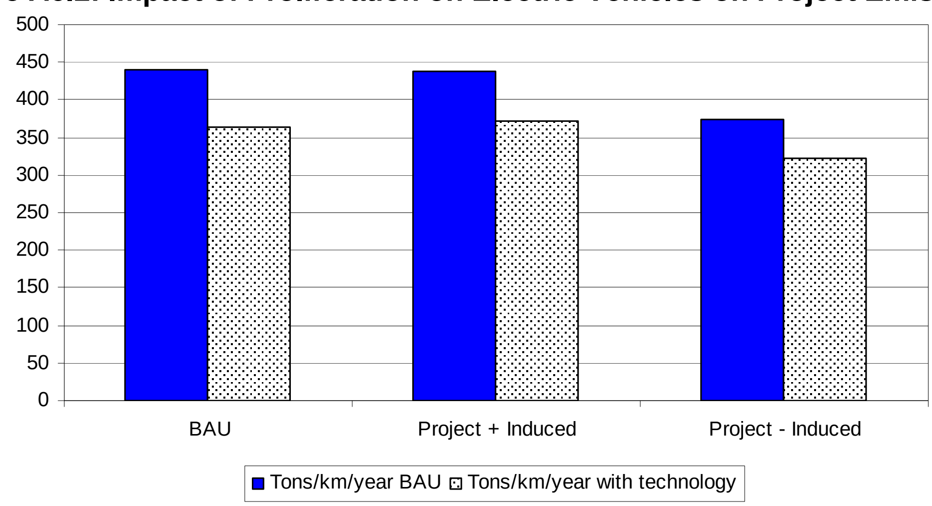
[1] The impact would be similar for with and without the project.
[2] International Energy Agency. 2005. *Saving Oil in a Hurry*. Paris; and various presentations made at the Ecodriven Conference on 12 November 2008. http://www.ecodrive.org/.../ecodrive/.../fuel_efficient _driving_training.pdf

some years.[3] To access the impact of eco-driving on project emissions, a uniform impact of 10% improvement in driver operating vehicle fuel efficiency after 5 years of project life was investigated. The quantification shows that there is a decrease of 9% in emissions (3,950 tons/km cumulatively over project life) when compared with the no eco-driving scenario. To achieve this magnitude of reductions, the driving needs to be made 11% more fuel-efficient (km per liter), indicating the need for sustained driving training in the catchment area of the project.

C. Proliferation of Electric Vehicles

5. To assess the impact of alternate vehicles on project emissions, a scenario of a rapid increase in the number of electric vehicles was considered. The scenario consisted of an increase in the mode share of electric vehicles to 30% at the end of the project life. The impact was tested on a road funded by the Asian Development Bank in Kazakhstan and Kyrgyz Republic (Almaty–Bishkek Regional Road Rehabilitation Project). The electric cars share was increased after 8 years of project initiation, and a 30% share was achieved in the next 3 years.[4] The impact was estimated to be savings of a cumulative 15% (1,300 tons/km) reduction from the scenario without electric vehicles. To achieve such technological penetration in the next 20 years is very challenging, and would require the implementation of several intense measures. Further, the vehicles renewal in such a short period is difficult, requiring a mix of techno-regulatory-finance measures. Figure A6.2 shows the impact on three scenarios—business as usual, with, and without induced traffic.

Figure A6.2: Impact of Proliferation on Electric Vehicles on Project Emissions



BAU = business as usual, km = kilometer.
Source: Independent Evaluation Department analysis based on data from Almaty–Bishkek Regional Road Rehabilitation Project.

6. Therefore, implementation of technological solutions may reduce some emissions in the long term, but significant efforts need to be made in implementing such policies, with efforts in synchronizing with demand-focused actions.

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[3] Many studies show a gradual degradation of impact as the sustained training is not carried out. In this analysis, such degradation rates have not been used and it has been assumed that sustained driver training in the catchment would sustain the momentum.

[4] Such a high increase is rather difficult, and requires an aggressive regulatory-legal-financial-technological approach.

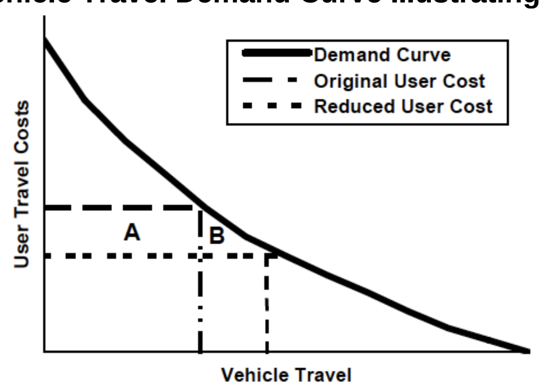
AN INDUCED DEMAND PRIMER

1. When considering the cost-effectiveness of low carbon transport strategies in relation to highway investments, it is important to consider the impacts of traffic that is generated by new or expanded road construction. Such traffic provides consumer benefits by increasing mobility, but the marginal value of these trips is often low.[1]

2. Economists estimate the benefits of additional travel at half the per-trip savings experienced by prior travelers. The area "B" shown in Figure A7.1 illustrates this relationship, the so-called "Rule of Half." When user costs in travel time or cost decrease, shown as a downward shift on the y-axis, this spurs more vehicle travel, shown as a rightward shift on the x-axis. Rectangle A shows the savings to existing trips, while Triangle B shows the generated travel benefits.

3. Economic analysis that does not fully account for generated and induced travel tends to overestimate the benefits of highway capacity expansion and to underestimate the benefits of sustainable low carbon alternatives to highway expansion, such as transport pricing reforms, public transport investment, traffic management, and nonmotorized travel improvements.[2] Many newer project evaluation models, such as the United States of America's Federal Highway Administration's Spreadsheet Model for Induced Travel Estimation sketch planning program, incorporate generated traffic effects.[3]

Figure A7.1: Vehicle Travel Demand Curve Illustrating the Rule of Half



Source: T. Litman. 2001. Generated Traffic and Induced Travel: Implications for Transport Planning. *ITE Journal*. 71(4). pp. 38–47. Institute of Transportation Engineers.

4. The Asian Development Bank needs to similarly account for such effects in all of its transport project appraisals, which it could do by adopting the transport emissions evaluation model for projects (TEEMP) developed by this evaluation knowledge brief as a standard tool for greenhouse gas appraisal and adapting this for economic analysis.

5. An example of such user benefits analysis by T. Litman, using an identical set of approaches to those employed in the TEEMP, is illustrative of what can be made part of standard practice for the Asian Development Bank's economic analysis, considering induced and generated traffic in road project appraisal (Box A7).

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[1] K. Small. 1998. Project Evaluation. *Essays in Transportation Economics and Policy*. Brookings Institution. Washington, DC.

[2] P. Romilly. 2004. Welfare Evaluation with A Road Capacity Constraint. *Transportation Research A*. 38(4). pp. 287–303.

[3] United States of America's Federal Highway Administration. *Spreadsheet Model for Induced Travel Estimation*. http://www.fhwa.dot.gov/steam/smite.htm

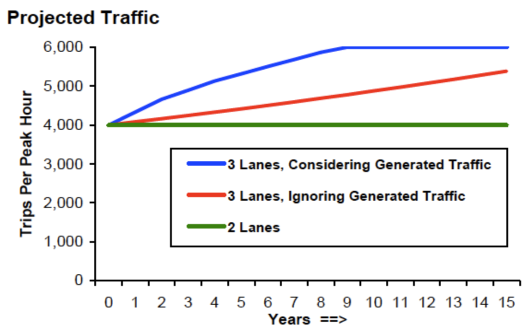
Box A7: Highway Expansion User Benefits Sensitivity Analysis – Case Study

A four-lane, 10-kilometer highway connects a city with nearby suburbs. The highway is congested 1,000 hours per year in each direction. Travel demand is predicated to grow at 2% per year. A proposal is made to expand the highway to six lanes, with $25 million in capital cost and $1 million in added annual highway operating cost.

Source: T. Litman. 2009. *Generated Traffic and Induced Travel: Implications for Transport Planning*. Victoria Transport Policy Institute.

6. Based on the case provided in Box A7, the following section analyzes the impact of induced traffic. Figure A7.2 shows predicted traffic. Without the project, peak-hour traffic is limited to 4,000 vehicles per direction, the maximum capacity of the two-lane highway. If generated traffic is ignored, the model predicts that traffic will grow at 2% per year if the project is implemented. If generated traffic is considered, the model predicts faster growth, including the basic 2% growth plus additional growth caused by generated traffic until volumes level off at 6,000 vehicles per hour, the maximum capacity of three lanes.

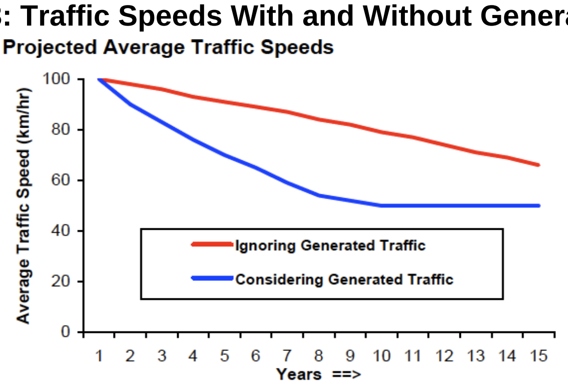
Figure A7.2: Traffic Growth With and Without Generated Traffic



Source: T. Litman. 2009. *Generated Traffic and Induced Travel: Implications for Transport Planning*. Victoria Transport Policy Institute.

7. The Litman model divides generated traffic into diverted trips (changes in trip time, route and mode) and induced travel (increased trips and trip length), using the assumption that the first year's generated traffic represents diverted trips and later generated traffic represents induced travel. This simplification appears reasonable since diverted trips tend to occur in the short term, while induced travel is associated with longer-term changes in consumer behavior and land use patterns. Roadway volume to capacity ratios are used to calculate peak-period traffic speeds, which are then used to calculate travel time and vehicle operating cost savings. Congestion reduction benefits are predicted to be significantly greater if generated traffic is ignored (Figure A7.3).

Figure A7.3: Traffic Speeds With and Without Generated Traffic



Source: T. Litman. 2009. *Generated Traffic and Induced Travel: Implications for Transport Planning*. Victoria Transport Policy Institute. http://www.vtpi.org/gentraf.pdf

8. Incremental external costs are assumed to average $0.10 per vehicle-kilometer for diverted trips (shifts in time, route, and mode) and $0.30 per vehicle-kilometer for induced travel (longer and increased trips). User benefits of generated traffic are calculated using the Rule of Half. Three cases were considered for sensitivity analysis: (i) most favorable uses assumptions most favorable to the project, (ii) medium uses values considered most likely, and (iii) least favorable uses values least favorable to the project. Table A7 summarizes the analysis.

Table A7: Assumptions and Economic Analysis Findings for Three Cases

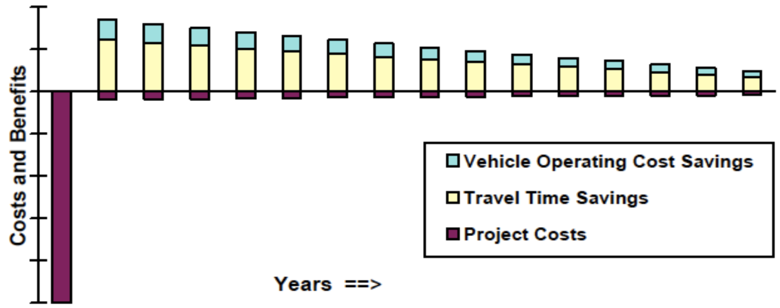
Data Input	Most Favorable	Medium	Least Favorable
Generated traffic growth rate	L	M	H
Discount rate	6%	6%	6%
Maximum peak vehicles per lane	2,200	2,000	1,800
Before average traffic speed (kph)	40	50	60
After average traffic speed (kph)	110	100	90
Value of peak-period travel time per vehicle-hour ($)	12.00	8.00	6.00
Vehicle operating costs per km ($)	0.15	0.12	0.10
Annual lane hours at capacity each direction	1,200	1,000	800
Diverted trip external costs per km ($)	0.00	0.10	0.15
Induced travel external costs per km ($)	0.20	0.30	0.50
Net Present Value (million)			
NPV without consideration of generated traffic ($)	204.8	45.2	(9.8)
NPV with consideration of generated traffic ($)	124.5	(32.1)	(95.7)
Difference ($)	**(80.3)**	**(77.3)**	**(85.8)**
Benefit/Cost Ratio			
Without generated traffic	6.90	2.30	0.72
With generated traffic	3.37	0.59	0.11

km = kilometer, kph = kilometer per hour, NPV = net present value.

Source: Adapted from T. Litman. 2009. *Generated Traffic and Induced Travel: Implications for Transport Planning*. Victoria Transport Policy Institute.

9. The most favorable assumptions result in a positive benefit–cost ratio even considering generated traffic. The medium assumptions result in a positive benefit–cost ratio if generated traffic is ignored but a negative net present value (NPV) if generated traffic is considered. The least favorable assumptions result in a negative benefit–cost ratio even when generated traffic is ignored. In each case, considering generated traffic has significant impacts on the results. Figure A7.4 illustrates project benefits and costs based on "medium" assumptions, ignoring generated traffic. This results in a positive NPV of $45.2 million, implying that the project is economically worthwhile.

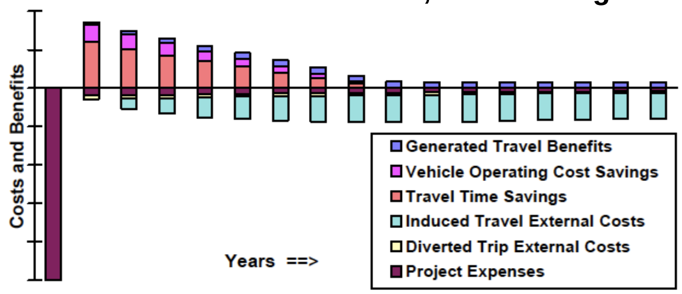
Figure A7.4: Estimated Benefits and Costs Ignoring Generated Traffic



Source: Adapted from T. Litman. 2009. *Generated Traffic and Induced Travel: Implications for Transport Planning*. Victoria Transport Policy Institute.

10. Figure A7.5 illustrates project evaluation when generated or induced traffic is considered. Congestion reduction benefits decline, and additional external costs and consumer benefits are included. The NPV is –$32.1 million, indicating the project is not worthwhile. This figure illustrates benefits and costs when generated traffic is considered using medium assumptions. Benefits are bars above the baseline; costs are bars below the baseline. It includes consumer benefits and external costs associated with generated traffic. Travel time and vehicle operating cost savings end after about 10 years, when traffic volumes per lane return to pre-project levels, resulting in no congestion reduction benefits after that time.

Figure A7.5: Estimated Costs and Benefits, Considering Generated Traffic



Source: Adapted from T. Litman. 2009. *Generated Traffic and Induced Travel: Implications for Transport Planning*. Victoria Transport Policy Institute.