ADB

METHODOLOGY FOR ESTIMATING CARBON FOOTPRINT OF ROAD PROJECTS

Case Study: India

Asian Development Bank

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FOREWORD

Methodology for Estimating Carbon Footprint of Road Projects started a couple of years ago with a simple question: how can the South Asia Transport and Communications Division assist in developing a carbon emission calculation methodology—an important milestone in future project evaluation?

We know our strength lies in our access to transport projects and the data related to them. Therefore, we embarked on a journey to research existing methodologies of carbon footprint estimation, refine the carbon footprint calculation model, and then collect data to test the model. The process has been interesting and rewarding. Some findings validated much of the common understanding we had about measuring the carbon footprint of road projects, and now we additionally have field data to support those conclusions.

I would like to thank many officials in India for their assistance. Without their generous support in providing access to documents and facilitating field visits and interviews, our work would not have been possible. Within ADB, I would like to thank Ms. Dewi Utami for initiating the study, Ms. Susan Lim for overseeing the study to completion, and Ms. Maria Cecilia Paña for assisting throughout the study. On the consultant side, I would like to thank Ms. Akshima Ghate and Mr. Peter King for tirelessly contributing their valuable knowledge and experience to our work.

This report is by no means the last word on finding the right method to measure carbon emissions in ADB-funded road projects; however we hope we have provided some field knowledge to others in the sector who may have difficultly accessing data. We further hope that this leads to greater refinement and development of a robust carbon footprint model for transport projects that will benefit us all.

Sri Widowati
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ABBREVIATIONS

ADB	–	Asian Development Bank
CF	–	carbon footprint
CNG	–	compressed natural gas
CO_2	–	carbon dioxide
DMC	–	developing member country
DPR	–	detailed project report
GHG	–	greenhouse gas
IRF	–	International Road Federation
LCV	–	light commercial vehicle
LDO	–	light diesel oil
LPG	–	liquefied petroleum gas
MP	–	Madhya Pradesh
NH	–	national highway
RR	–	rural road
SARD	–	South Asia Department
SH	–	state highway
UP	–	Uttar Pradesh

WEIGHTS AND MEASURES

kg	–	kilogram
kl	–	kiloliter
km	–	kilometer
kWh	–	kilowatt-hour
l	–	liter
m	–	meter
m^3	–	cubic meter
mt	–	metric ton

PROLOGUE

Strategy 2020 of the Asian Development Bank (ADB) provides a clear, strategic direction to strengthen ADB's operational emphasis on the environmentally sustainable growth for the region, with special focus on climate change, especially to assist the developing member countries (DMCs) move their economies onto a low-carbon growth path. Strategy 2020 also clearly describes ADB's continued investment in infrastructure to improve transport and communication connectivity within and between DMCs.

In the transport sector, ADB is involved in improving all transport modes, such as railway, inland water, and road. The road sector has contributed significantly to the operations of ADB's South Asia Department (SARD). In 2000, the approved loans for the road sector totaled $384.6 million or about 20% of SARD loans and grants. In 2009, the approved loans and grants for the road sector amounted to $683.8 million; it contributed about 19% to SARD operations.

In the context of assisting DMCs to slow down their contribution to the increase in greenhouse gases (GHGs) as part of ADB's efforts to promote a low-carbon growth path in the transport sector, the current operations of ADB have emphasized promoting "clean fuel," improving traffic management in the urban sector, and promoting mass public transport. These efforts would not be adequate, considering that in most DMCs, roads are still the most important infrastructure. Therefore, ADB support through road construction, improvement, and rehabilitation will continue. Road improvement will lead to the smooth movement of vehicles, which will also lead to the opening of public transport, and will likely minimize the use of fuel and lead to reduced carbon dioxide (CO_2), one important contributor to GHGs. On the other hand, construction works related to improvement and rehabilitation of existing roads may generate GHGs. Therefore, it is necessary to assess the benefits and costs of road construction and improvement and costs related to their contribution to GHG decrease or increase. This will enable ADB to provide recommendations for DMCs on a low-carbon growth path in the road sector and to mainstream the low-carbon growth approach in SARD operations.

Carbon footprint is a tool commonly used to describe the total amount of CO_2 and other GHG emissions for which an individual or organization is responsible. Footprints can also be calculated for activities, events, or products. There are no studies on the assessment of carbon footprint in road construction and improvement activities that ADB could directly use because of the nature and type of its activities in this sector. In this context, the South Asia Transport and Communications Division (SATC) carried out this study to explore possible approaches and methods to calculate the carbon footprint from its road activities, and to calculate total contributions on its overall activities in India. India was selected for this study because it represents all types of SARD activities (highways, national roads, and rural roads) and the project locations range from urban to rural areas with different ecological conditions. In this context, this is a pilot study to derive a carbon footprint calculation methodology of SARD road operations and use the SARD road projects in India to examine the robustness of the methodology.

INTRODUCTION

Understanding Carbon Footprint

Carbon footprint is a commonly used term to describe the total amount of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions for which an individual or organization is responsible. It is usually defined as the total amount of CO_2 and other GHGs emitted over the full life cycle of a product or service. Carbon footprint can be calculated for activities, events, or products and analyzed at the national or sector, corporate, and household or individual levels.

Carbon Footprint of the Road Sector—Brief Review of Approaches Used

In line with the definition given above, the carbon footprint of a road can be defined as the total amount of CO_2 and other GHGs (direct and indirect) emitted over the full life cycle of a road. Said life cycle includes construction, operation, and maintenance phases. Its "life" ends when the road needs to be completely reconstructed or when it is abandoned.

Generally, carbon emissions are calculated at a national level, often using methodologies and default values suggested by the Intergovernmental Panel on Climate Change (IPCC). These national estimates include sectoral estimations, which are based on detailed sectoral analysis. A few nations have carried out carbon inventories for the road sector to analyze its contribution to total transport sector–generated GHG emissions. New Zealand's Ministry of Transport has undertaken modeling to understand the factors that control road transport's contribution to CO_2 emissions and the potential impacts of proposed mitigation measures at the national, sector level (Office of the Minister of Transport 2001). New Zealand developed a Vehicle Fleet Fuel Model to quantify likely increases in CO_2 emissions in the absence of policy interventions and with possible policy interventions compared with requirements under the Kyoto Protocol. To predict CO_2 emissions, the model uses variables such as expected population growth, future levels of economic development, and the changing composition of the vehicle fleet.

For different modes of transport, the United Kingdom (UK) uses the following CO_2 conversion factors (in grams CO_2 per passenger-kilometer traveled): (i) private car, medium petrol hybrid – 80; (ii) private car, medium diesel (1.7–2.0 liters) – 120; (iii) private car, medium petrol (1.4–2.0 liters) – 137; and (iv) bus – 90. Most major roads in the UK have regular road-side traffic counts, which can be multiplied by fuel-efficiency ratios and CO_2 conversion factors to calculate the carbon footprint.

Many carbon footprint calculations are based on household or individual consumption behavior with a view to influencing changes in behavior toward a more energy-efficient lifestyle. Typically, these footprint calculators merely require the user to input the make and model of their car and an estimate of the kilometers traveled over a month or year. More detailed estimates are based on fuel efficiency of the vehicle and variations based on driving behavior (DEFRA 2007). Other factors identified, but normally not included in the calculators, are vehicle payload, travel racks or other accessories that increase aerodynamic drag, poor maintenance, incorrect tire pressure, terrain factors, weather, or aggressive driving styles and heavy braking. The state of the roads is not a factor in any of the calculators reviewed.

The International Road Federation (IRF) states that improving traffic fluidity, reducing congestion, and hence lowering fuel consumption is an effective way of reducing GHG emissions. Specific measures and their potential to reduce GHG emissions include (i) enlarging the road network (40%), (ii) replacing crossroads with bridges (30%), (iii) building bypasses (25%), (iv) eliminating level crossings (13.5%), (v) pre-selection at traffic lights (15%), (vi) traffic flow management (30%), (vii) synchronized traffic lights (40%), (viii) traffic jam reduction (22%), (ix) management of urban traffic (40%), (x) management of ex-urban traffic (30%), and (xi) management of traffic on motorways (20%) (IRF undated).

The impact of driving behavior on fuel consumption and GHG emissions is an interesting, if underestimated, factor. For example, under-inflated tires can increase fuel consumption by 1% per 3 pounds per square inch (PSI) under-inflation (typical pressure is 30–35 PSI); air-conditioning causes a 20%–25% increase when on full power; and eco-driving and dropping average speed can reduce fuel consumption by 5%–10% (DEFRA 2007). Reducing the speed limit on motorways to 100 kilometers per hour and enforcing it appropriately reduces emissions by about 18%. France enforced strict speed limits in 2004 and reduced carbon emissions by 19% and accidents by 30% (House of Commons 2006).

The IRF, in conjunction with the Borneo Tropical Rainforest Foundation, Scott Wilson Group, and other partners, is designing a methodology for the "calculation and modeling of emission estimates, in carbon equivalency, of road construction and maintenance projects" (IRF 2007). Originally intended to be rolled out in 2008, the model is expected to incorporate emissions from road construction materials, fuel consumption, construction site energy use, and administration.

The state of Victoria in Australia, through its road agency, VicRoads, has carried out one of the few studies on GHG emissions from road construction (VicRoads 2008). In this case, the carbon footprint was calculated by identifying the amount of GHG emissions from (i) on-site electricity, (ii) transport of materials to the site, (iii) embodied energy of materials, and (iv) on-site transport. The model, however, does not cover carbon footprint estimation methodology for road operation and maintenance phases.

Objective of the Study

This study aims to estimate the carbon footprint of ADB-funded road construction and/or improvement projects in India to come up with a comprehensive approach for calculating the carbon footprint from road construction, operation, and maintenance phases.

METHODOLOGY

Framework for Estimating the Carbon Footprint of Selected ADB-Funded Roads in India

Before undertaking the study in India, carbon footprinting methodologies, as discussed in the Introduction, were reviewed. It was observed that none of the reviewed methodologies focused on estimating the total life cycle CO_2 emissions from road projects. A carbon footprint framework was developed, therefore, to estimate total CO_2 emissions from the full life cycle of any road in India. As a first step toward developing this framework, it was recognized that understanding all possible sources of direct and indirect CO_2 emissions during the full life period of any road is vital. The possible sources of CO_2 emissions (direct and indirect) during any road cycle are discussed below.

Road Construction Phase

(i) Construction materials

Embodied carbon in construction materials—CO_2 emissions are released during the production of construction materials. The production process includes extraction or mining of raw materials, transportation, processing, and distribution. These emissions are indirect emissions as they are not released at the construction site but elsewhere. Hereafter these indirect emissions will be referred as "embodied carbon." Embodied carbon refers to CO_2 emissions at all stages of a good's production process, starting from extraction of raw materials until distribution of the finished good to the consumer.

(ii) Fossil fuels

(a) **Direct emissions due to combustion of fossil fuels**—Fossil fuels such as diesel, furnace oil, and light diesel oil (LDO), among others, are used at road construction sites in different types of construction machinery and vehicles. The combustion of these fossil fuels in engines results in direct CO_2 emissions.

(b) **Embodied carbon in fossil fuels**—Fossil fuels used at construction sites also have life cycle CO_2 emissions or embodied CO_2 emissions released during the production and distribution of these fossil fuels. The production of fossil fuels involves raw fuel extraction, transportation, processing, and distribution stages, all of which emit CO_2.

(iii) Removal of vegetation

(a) **Carbon sequestration potential lost**—Road construction requires clearance of vegetation that may lead to a certain amount of carbon sequestration potential being lost. However, the road contractors are usually required to plant new trees to compensate the tree loss, hence, making up for the sequestration potential lost on account of trees cut during construction. We therefore do not include the CO_2 sequestration potential lost due to removal of vegetation in the carbon footprint accounting of the road project where planting of new trees will compensate for this loss.

(b) **Direct emissions due to combustion of fuel wood**—The trees removed from the construction site may be put to different end uses such as timber, fuel wood, etc. If the trees or their parts are being used as fuel wood in manufacturing units, households, construction camps, etc., the combustion of fuel wood would contribute to direct CO_2 emissions. We include this CO_2 loss on account of wood burning in the carbon footprint of the road section being constructed.

(iv) Construction machinery and vehicles

Embodied carbon in machinery and vehicles—Different types of machinery and vehicles are used during the road construction and maintenance phases; production of these machinery and vehicles leads to CO_2 emissions. These emissions, however, are not accounted in the carbon footprint of the road, as the same construction machinery and vehicles would be used to construct a number of roads. Accounting for the embodied carbon of these in the carbon footprint of all roads may result in multiple counting. The embodied carbon in construction machinery and vehicles is therefore excluded from the carbon footprint of the road. Theoretically, however, calculating the kilometers of roads constructed by each piece of machinery in its lifetime and attributing a portion of the embodied carbon to the road in question are possible.

Road Operation Phase

(i) Fossil fuels

(a) **Direct emissions due to combustion of fossil fuels**—The road operation phase involves movement of motorized vehicles that emit CO_2 due to fuel combustion. CO_2 emitted by vehicles moving on the road is included in the carbon footprint of the road.

(b) **Embodied carbon in fossil fuels**—Fossil fuels used in the vehicles have a life cycle CO_2 emissions or embodied CO_2 emissions released during production and distribution of these fossil fuels. These embodied emissions are included in the carbon footprint of the road.

(ii) Vehicles

Embodied carbon in vehicles—The vehicles moving on roads also have embodied carbon that is emitted during the production of vehicles. This, however, is not accounted in the carbon footprint of the road to avoid multiple counting. The same vehicle will move on different roads and if its embodied carbon was included in the carbon footprint of all road sections, it would lead to multiple counting. Although the embodied carbon in vehicles is not included in the carbon footprint of the road, it should be included in a carbon footprint of the entire national road sector. As for construction equipment, it would be possible theoretically to calculate the average number of kilometers each type of vehicle covers and calculate the proportion expended on the road being examined. However, this would involve multiple assumptions and considerable uncertainty.

Road Maintenance Phase (Routine and Periodic)

(i) Construction materials

Embodied carbon in construction materials—Road maintenance works require construction materials, all of which have embodied carbon on account of their production and extraction process.

(ii) Fossil fuels

(a) **Direct emissions due to combustion of fossil fuels**—Road maintenance requires use of fossil fuels in different types of construction machinery and vehicles. The combustion of these fossil fuels results in direct CO_2 emissions.

(b) **Embodied carbon in fossil fuels**—Fossil fuels used during maintenance works have embodied carbon content on account of their production and distribution process, and this is included.

The CO_2 emissions sources included in the carbon footprint of the entire life cycle of a road are summarized in Table 1.

Table 1. Carbon Footprint of a Road and Sources of CO_2 Emissions

CO_2 Sources	Construction Materials	Fossil Fuels		Removal of Vegetation		Machinery/ Vehicles
Road Life Cycle Stages	Embodied Carbon	Embodied Carbon	Direct CO_2 Emissions	Carbon Sequestration Potential Lost	Direct CO_2 Emissions	Embodied Carbon
Road Construction	√	√	√	√	√	X
Road Operation	X	√	√	X	X	X
Road Maintenance	√	√	√	X	X	X

CO_2 = carbon dioxide.

Source: This study.

After identifying the sources of CO_2 emissions to be accounted while estimating the carbon footprint of a road (Table 1), the detailed carbon footprint estimation model was prepared. This model has three parts, namely, road construction, road operation, and road maintenance. The scope of the model is discussed on the next page.

Road construction phase

(i) **On-site CO_2 emissions**

- electricity use (electricity purchased from the grid)
- generation of electricity using diesel generators
- use of fuels in construction machinery
- use of fuels in vehicles
- vegetation removed

(ii) **CO_2 emissions due to transportation of construction materials to the site**
use of fuel in vehicles used for transporting construction materials to the site

(iii) **Embodied carbon**

- in construction materials used
- in fuels used

Road operation phase

(i) **CO_2 emissions due to vehicular movement on road**
fuel used by all types of vehicles moving on the road throughout its life cycle

(ii) **Embodied carbon**
in fuels used

Road maintenance phase

(i) **On-site CO_2 emissions**

- use of fuels in construction machinery
- use of fuels in vehicles

(ii) **Embodied carbon**

- in construction materials used
- in fuels used

Selected Road Projects and Data Collection

Four reasonably "typical" ADB-funded road projects were selected and primary field surveys were carried out to collect data as the carbon footprint framework required (Table 2). The criteria for selection of sample projects were

- type of road, i.e., national highway, state highway, or rural road
- location (state, terrain)
- type of improvement works
- stage of construction

Table 2. Detailed Framework Developed for Estimating the Carbon Footprint of Road Construction and/or Improvement Projects

	CO_2 Source	Unit	Emission Factor
Construction phase			
On-site electricity and fuel usage			
Units of electricity purchased from grid	Electricity	kWh	kg CO_2/kWh
Diesel used in generators	Diesel	l	kg CO_2/l
Diesel used in fixed and movable machinery	Diesel/furnace oil/LDO	l	kg CO_2/l
Diesel used in vehicles	Diesel	l	kg CO_2/l
Petrol used in vehicles	Petrol	l	kg CO_2/l
Any other fuel used on-site	Fuel	l/m^3	kg CO_2/l/m^3
Vegetation removed			
Biomass used as fuel wood	Fuel wood	kg	kg CO_2/kg
Fuel used in transportation of materials to/from site			
Cut exports	Diesel	l	kg CO_2/l
Fill imports	Diesel	l	kg CO_2/l
Aggregate/base material	Diesel	l	kg CO_2/l
Cement	Diesel	l	kg CO_2/l
Bitumen	Diesel	l	kg CO_2/l
Emulsion	Diesel	l	kg CO_2/l
Steel reinforcement	Diesel	l	kg CO_2/l
Other steel	Diesel	l	kg CO_2/l
Furnace oil and LDO	Diesel	l	kg CO_2/l
Diesel	Diesel	l	kg CO_2/l
Any other material transported	Diesel	l	kg CO_2/l
Embodied carbon in construction materials and fuels used			
Construction materials	Aggregate/base material	t	kg CO_2/t
	Cement	t	kg CO_2/t
	Bitumen	t	kg CO_2/t
	Emulsion	t	kg CO_2/t
	Steel reinforcement	t	kg CO_2/t
	Other steel	t	kg CO_2/t
	Other materials	t	kg CO_2/t

(continued on next page)

Table 2 *(continued)*

	CO_2 Source	Unit	Emission Factor
Fuels	Furnace oil and LDO	l	kg CO_2/l
	Diesel	l	kg CO_2/l
	Petrol	l	kg CO_2/l
	Other fuels	l/m^3	kg CO_2/l/m^3
Operation phase			
Fuel usage by on-road traffic for entire life cycle of road (after the road becomes functional)			
Car	Petrol	l	kg CO_2/l
Taxi	Petrol	l	kg CO_2/l
Two-wheeler	Petrol	l	kg CO_2/l
Three-wheeler	Petrol	l	kg CO_2/l
Any other vehicle	Petrol	l	kg CO_2/l
Car	Diesel	l	kg CO_2/l
Taxi	Diesel	l	kg CO_2/l
Two-wheeler	Diesel	l	kg CO_2/l
Three-wheeler	Diesel	l	kg CO_2/l
Bus	Diesel	l	kg CO_2/l
Minibus	Diesel	l	kg CO_2/l
LCV	Diesel	l	kg CO_2/l
HCV	Diesel	l	kg CO_2/l
Any other vehicle	Diesel	l	kg CO_2/l
Car	LPG	m^3	kg CO_2/m^3
Taxi	LPG	m^3	kg CO_2/m^3
Three-wheeler	LPG	m^3	kg CO_2/m^3
Any other vehicle	LPG	m^3	kg CO_2/m^3
Car	CNG	m^3	kg CO_2/m^3
Taxi	CNG	m^3	kg CO_2/m^3
Three-wheeler	CNG	m^3	kg CO_2/m^3
Bus	CNG	m^3	kg CO_2/m^3
Any other vehicle	CNG	m^3	kg CO_2/m^3
Embodied carbon in fuels used			
Fuels	Petrol	l	kg CO_2/l
	Diesel	l	kg CO_2/l
	LPG	m^3	kg CO_2/m^3
	CNG	m^3	kg CO_2/m^3

(continued on next page)

Table 2 *(continued)*

	CO_2 Source	Unit	Emission Factor
Maintenance phase			
Embodied carbon in construction materials and fuels used			
Construction materials	Bitumen	t	kg CO_2/t
	Emulsions	t	kg CO_2/t
	Aggregate	t	kg CO_2/t
	Any other material	t	kg CO_2/t
Fuels	Furnace oil/LDO	t	kg CO_2/t
	Diesel	t	kg CO_2/t
	Petrol	t	kg CO_2/t
	Other fuels	l/m^3	kg CO_2/l/m^3
Fuel used on-site			
Fixed and movable machinery	Diesel/furnace oil/LDO	l	kg CO_2/l
Any other fuel used on-site	Fuel	l/m^3	kg CO_2/l/m^3
Fuel used in transportation of materials to/from site			
Bitumen	Diesel	l	kg CO_2/l
Emulsions	Diesel	l	kg CO_2/l
Aggregate	Diesel	l	kg CO_2/l
Any other material	Diesel	l	kg CO_2/l

CNG = compressed natural gas, CO_2 = carbon dioxide, HCV = heavy commercial vehicle, kg= kilogram, l = liter, LCV = light commercial vehicle, LDO = light diesel oil, LPG = liquefied petroleum gas, m^3 = cubic meter, t = ton.

Source: This study.

Table 3 details the selected sample projects.

Field visits were carried out and primary data were collected from the road contractors according to a questionnaire. Additional details were sought from appraisal reports, project design documents, procurement contracts, and other relevant project documents. To the extent possible, secondary data were sourced from standard project design reports. Traffic volume projections for the roads were taken from the modeling exercises that underpin the economic analysis undertaken at the feasibility study phase, subject to subsequent sensitivity testing.

Methodology for Estimating the Carbon Footprint of Total ADB Road Portfolio in India

The carbon footprint results for the sample projects (Table 3) selected for the study were used to estimate the carbon footprint of ADB's entire road sector portfolio in India. The ADB road portfolio was classified into four broad categories—national highway (NH), state highway (SH) in flat terrain, SH in hilly terrain, and rural roads. The information provided by ADB was used to calculate the total length of these road categories in the ADB portfolio. The road lengths for different road types were then multiplied by the respective average annual value of the carbon footprint derived from the sample projects to estimate the total carbon footprint of ADB portfolio in 2008.[1] All road projects in ADB's portfolio may be at different life stages in 2008. Some may be under construction and others under operation. The footprint estimate is an average estimate for 1 year, considering the economic life of different types of roads.

Table 3. Details of Sample Road Projects

No.	Project Name	Type of Road	State	Terrain	Length (km)	Existing Width of Road or No. of Lanes	Type of Improvement
1.	EW-II (MP-1, MP-2, and MP/UP-1)	National highway	Madhya Pradesh and Uttar Pradesh	Flat	128.3	2 lanes	Rehabilitation and upgrading to 4 lanes
2.	MPSRSP-II, Package 4 (Road No. 7) Barwah-Dhamnod road, Khalghat-Manawar road, and Khalghat-Kasarwad road	State highway	Madhya Pradesh	Flat	123.0	7 m	Construction of overlays widening and new construction of roadway
3.	USRIP-I, Package 1 (District Dehradun) Kalsi-Chakrata road	State highway	Uttarakhand	Hilly	40.0	6 m	Widening, strengthening, and maintenance of existing pavement
4.	WB-05-ADB-09 (Jamalpur Block, Bardhaman District) Karalaghat–Krihnarampur road	Rural road	West Bengal	Flat	5.8	1 lane (effective width)	New road (Converting the existing kutcha road to all-weather rural road)

ADB = Asian Development Bank, EW = East–West, km = kilometer, m = meter, MP = Madhya Pradesh, MPSRSP-II = Madhya Pradesh State Roads Sector Project, UP = Uttar Pradesh, USRIP-I = Uttarakhand State Roads Investment Project I, WB = West Bengal.

Source: Detailed project reports.

[1] Using a sample of four projects to estimate total ADB road sector portfolio emissions generates some uncertainty in the results as the sample size is small: one limitation of this study. The uncertainty can be reduced by increasing the sample size. However, it may also be noted that the main objective of this study was to develop and test the methodology to estimate the carbon footprint of road projects. The results of the study for sample projects have been used merely to demonstrate their application for estimating ADB's road sector portfolio's emissions in India.

FINDINGS

Carbon Footprint of Selected Roads

Carbon Footprint of Construction Phase

The carbon footprint of the construction phase for all sample projects was calculated from primary data collected from the road construction contractors. The direct sources of CO_2 emissions during the construction phase include on-site use of diesel, furnace oil, and light diesel oil (LDO) in construction machinery, vehicles, and power generators. The transport of construction materials to the site also contributes to CO_2 emissions. The indirect emissions are attributed to the embodied carbon in construction materials and fuels used on-site. Use of vegetation removed from construction site as fuel wood also contributes to direct CO_2 emissions.[2] Table 4 summarizes the amount of electricity purchased from the grid, diesel used on-site, and the number of trees cut for the four sample projects. Table 5 summarizes the amount of different types of construction materials used per kilometer during construction of the four sample roads, and Table 6 gives the total quantity of diesel used for transporting construction materials and/or fuels to the construction site.

Table 4. Electricity and Fuels Used On-Site and Vegetation Removed

Road Project	Electricity Purchased (kWh/km)	Diesel Used in Generators (kl/km)	Diesel Used On-Site (kl/km)	Furnace Oil and LDO Used On-Site (kl/km)	Trees Removed
NH, MP/UP	466.8	66.4	125.2	44.3	16,524
SH, MP	9,527.8	0.4	27.7	21.1	68
SH, Uttarakhand	202.5	0.2	3.1	0.6	0
RR, West Bengal	192.6	0.0	3.6	1.4	0

kl = kiloliter, km = kilometer, kWh = kilowatt-hour, LDO = light diesel oil, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Note: The electricity purchased per kilometer for the NH, MP/UP construction is less compared with the SH, MP construction because the NH, MP/UP depends on electricity from two sources: grid and diesel generators. Therefore, though it purchases less electricity from the grid, this road project generates its own electricity on-site to meet the construction demand. The diesel used per kilometer of road construction to generate electricity on-site is therefore highest for the NH, MP/UP. SH, MP meets all of its electricity needs by purchasing electricity from the regional grid. Also, the number of trees cut during NH, MP/UP construction is the highest compared with all other roads because this NH passes through forest areas and the construction activity required clearing of a number of trees.

Source: Road construction contractors, project documents, and bills of quantities.

[2] Some emissions may be due to diversion of traffic for facilitating construction activity. However, these emissions are not included in the analysis because of lack of data.

The total quantum of fuel and electricity consumed (for road construction and transport of construction materials and/or fuels to the site) was converted to equivalent CO_2 emissions using India-specific emission factors. Similarly the embodied CO_2 in construction materials and/or fuels used was estimated using India-specific values. The sources for emission factors and embodied energy values are discussed in the appendix. The CO_2 estimation results for the construction phase of all sample projects are found in Table 7.

Table 5. Construction Materials Used per Kilometer

Road Project	Aggregate/ Base Materials mt/km	Cement mt/km	Bitumen mt/km	Steel Reinforcement mt/km	Emulsion mt/km
NH, MP/UP	31,684.9	737.8	403.5	143.2	61.8
SH, MP	15,119.2	107.4	70.8	12.6	6.7
SH, Uttarakhand	550.5	78.1	20.7	2.1	1.8
RR, W. Bengal	74.8	6.8	4.6	0.0	1.5

km = kilometer, MP = Madhya Pradesh, mt = metric ton, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Source: Road construction contractors, project documents, and bills of quantities.

Table 6. Diesel Used for Transportation of Construction Materials/Fuels

Road Project	Total Diesel Used for Transportation of Construction Materials/ Fuels to the Site (kl)
NH, MP/UP	4,331.9
SH, MP	774.9
SH, Uttarakhand	148.7
RR, W. Bengal	60.5

kl = kiloliter, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Source: Road construction contractors, project documents, and bills of quantities.

Table 7. CO_2 Emissions from the Entire Construction Phase

Road Project	CO_2 (ton/km)
NH, MP/UP	2,115.2
SH, MP	377.9
SH, Uttarakhand	109.6
RR, W. Bengal	48.4

CO_2 = carbon dioxide, km = kilometer, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Source: This study.

Carbon Footprint of Operation Phase

The transport fuels used in vehicles during road operations contribute to direct and indirect CO_2 emissions on account of fuel combustion in vehicle engines and embodied carbon in fuels respectively. The cumulative GHG emissions are attributable to the increasing number of vehicles on the road, the number of kilometers traveled by each vehicle, the fuel consumed for each kilometer traveled, and the carbon content of the different fuels used.

Vehicular movement for the entire life period of the sample roads was estimated by using the data from detailed project reports (DPRs) and economic analysis of these sample projects. ADB accepts these vehicular projections in the DPRs for justifying the economic viability of the road construction. Since the road construction activity is based on these future vehicular projections, it is appropriate to use these traffic numbers for the entire project life. The vehicular projections in DPRs include the vehicular growth resulting from population increase and economic growth in the region (natural growth). This natural traffic growth is considered to be the normal growth of traffic that would have taken place with or without the road construction project. In addition to the natural growth of traffic volumes, road improvements also generate new traffic on account of better driving conditions. The projections for this "induced traffic" or "newly generated traffic" due to road improvements and diversion of traffic to these roads are also included in the DPR future traffic projections (sometimes explicitly, sometimes implicitly).

The DPRs of the sample road projects either give yearly projections for different transport modes or the growth rates for these modes. The vehicle projection data and/or growth rates from DPRs were used to derive the vehicle volumes for the design life of sample projects. The operation phase duration or the design life for the sample projects was taken as assumed in the DPRs (for national highway, Madhya Pradesh/Uttar Pradesh – 22 years; state highway, Madhya Pradesh – 30 years; state highway, Uttarakhand – 16 years; and rural road, W. Bengal – 10 years). The traffic estimates for the entire operation phase of sample road projects (natural traffic growth and induced traffic) are given in Table 8. The modal share of different transport modes during the entire design life of the roads is shown in Figure 1. These data are the same data that ADB and the Government of India use to justify investment in these projects.

CO_2 emissions from vehicles have been estimated considering key factors, such as technology changes, fuel mix in future, fuel efficiency improvements, and changes in annual mileage.

India-specific emission factors have been used to estimate the CO_2 emissions from vehicular movement. The sources for emission factors and for assumptions for technology, fuel mix, fuel efficiency, and annual mileage changes are discussed in the appendix.

The embodied CO_2 emissions in fuels on account of fuel extraction, production, and distribution have also been estimated and added to the direct CO_2 emissions from vehicular movement to estimate the total footprint of the operation phase.[3] The results of CO_2 emissions per kilometer for the entire operation phase are given in Table 9.

[3] As discussed previously, the traffic estimates for the total road life taken from DPRs include induced and diverted traffic numbers. However, all DPRs do not segregate the induced traffic from the normal traffic numbers and just give a total of the two. A separate analysis of emissions caused by normal traffic growth and induced traffic is not possible.

Table 8. Traffic Estimates for Total Operation Phase of Sample Projects (in vehicle numbers)

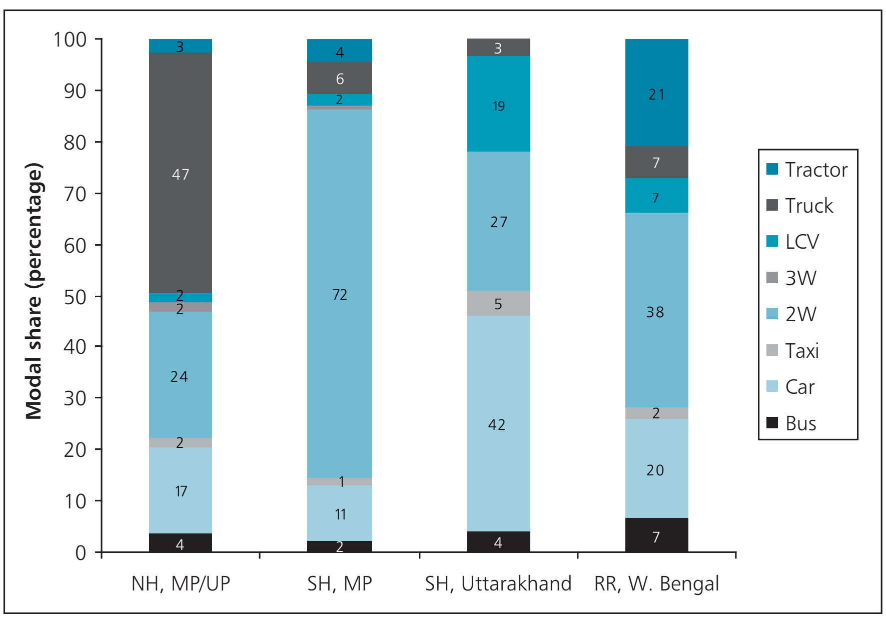
Vehicle Type	NH, MP/UP	%	SH, MP	%	SH, Uttarakhand	%	RR, W. Bengal	%
Bus	50,336	4	13,408	2	443	4	107	7
Car/jeep/van	228,942	17	60,065	11	4,786	42	321	20
Taxi	25,438	2	6,674	1	532	5	36	2
Two-wheeler	334,636	24	402,301	72	3,049	27	624	38
Auto rickshaw	27,602	2	2,321	0	0	0	0	0
LCV	24,942	2	13,849	2	2,110	19	107	7
Truck	639,252	47	35,740	6	382	3	107	7
Tractor	35,892	3	23,943	4	0	0	339	21
Total	1,367,040	100	558,302	100	11,302	100	1,640	100

LCV = light commercial vehicle, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Note: The operation phase durations for NH, MP/UP; SH, MP; SH, Uttarakhand; and RR, W. Bengal are 22, 30, 16, and 10 years respectively. These durations have been taken from the detailed project reports of these sample road projects, following the principle of using data that ADB already accepts as part of the project design.

Source: Detailed project documents.

Figure 1. Modal Share on Sample Roads (for the entire design life)



LCV = light commercial vehicle, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh, W = wheeler.

Source: Detailed project documents.

Table 9. CO_2 Emissions from the Entire Operation Phase

Road Project	CO_2 (ton/km)
NH, MP/UP	72,753.9
SH, MP	22,465.7
SH, Uttarakhand	1,695.3
RR, W. Bengal	1,425.2

CO_2 = carbon dioxide, km = kilometer, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Notes: The operation phase duration for all sample road projects (taken from detailed project reports) is different (NH, MP/UP – 22 years; SH, MP – 30 years; SH, Uttarakhand – 16 years; and RR, W. Bengal – 10 years).

Table 9 shows a significant difference in per-kilometer emissions from the operation phase for the state highways in MP and in Uttarakhand, which may seem counterintuitive. The main reasons for this are the following:

- Difference in the traffic intensity per kilometer on these two roads for the entire operation phase (MP state highway – 4,540 vehicles per km for 30 years and Uttarakhand state highway – 285 vehicles per km for 16 years)
- The terrain for the two roads is different (MP state highway – flat terrain and Uttarakhand state highway – hilly terrain)
- The state highway in Uttarakhand is remotely located. Also, there are restrictions with respect to entry of vehicular traffic on this highway due to security reasons. This state highway does not have much heavy vehicular traffic.
- Although the two roads serve as state highways, the widths of the two vary significantly due to the terrain in which they are located and the traffic densities. While the state highway in Uttarakhand has a two-lane carriageway, the state highway in MP has a carriageway of four lanes.

For the purposes of comparison with rural roads, the state highway, MP, is more appropriate than the Uttarakhand state highway, which may be more of an outlier.

Source: This study.

A 2007 report of ADB's Operations Evaluation Department (renamed Independent Evaluation Department) and a handful of project completion reports indicate that the actual traffic on completed roads is often lower than the traffic forecasts used at project appraisal. This study, however, still considers traffic forecasts used in economic analysis and DPRs as useful for estimating CO_2 emissions. The assumption is that over time consultants would have adjusted their models to be more accurate in their forecasts. Nevertheless, a sensitivity test was carried out to see the impact of lower or higher traffic volumes on CO_2 emissions. The results of the sensitivity test are shown in Table 10.

Table 10. Results of Sensitivity Test—Change in CO_2 Emissions with Increase and/or Decrease in Traffic in Operation Phase (for the total duration of operation phase, in tons)

Road Project	Traffic as per DPR Estimates	10% Less Traffic	20% Less Traffic	10% More Traffic	20% More Traffic
NH, MP/UP	9,334,322.9	8,400,890.6	7,467,458.3	10,267,755.2	11,201,187.5
SH, MP	2,763,279.4	2,486,951.4	2,210,623.5	3,039,607.3	3,315,935.3
SH, Uttarakhand	67,810.6	61,029.5	54,248.5	74,591.6	81,372.7
RR, W. Bengal	8,266.3	7,439.6	6,613.0	9,092.9	9,919.5

CO_2 = carbon dioxide, DPR = detailed project report, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Source: Detailed project reports and this study.

Carbon Footprint of Maintenance Phase

Significant maintenance works start after a few years of road operations. Maintenance works contribute to CO_2 emissions (direct and indirect) on account of on-site use of fuels and construction materials and transport of materials and/or fuels to the maintenance site. The maintenance phase data for the sample roads were not available because these roads are either under construction or have been completed recently. Therefore, as an alternative, roads similar[4] to the sample roads and under maintenance activities were identified with the help of executing agencies and contractors, and the collected data were used to estimate maintenance activity for sample roads. Per data collected, among the sample roads, about 10% of the road length of national highways and state highways in the plains, 50% of the road length of state highways in hilly areas, and about 70%–80% of the road length of rural roads would require significant maintenance works every year.[5] The summary of maintenance works contributing to CO_2 emissions is given in Table 11.

The CO_2 emissions from use of construction materials and fuels on-site and for transportation of materials and/or fuels to the site were estimated using appropriate emission factors (see appendix). The results are given in Table 12.

Table 11. Construction Materials and Fuels Used for All Maintenance Works Carried on Road for Its Total Life

Road Project	Hard Gravel (m^3/km)	Bitumen (mt/km)	Emulsions (mt/km)	Aggregate (mt/km)	Diesel Usage On-site (kl/km)	Diesel Usage for Transport of Materials (kl/km)
NH, MP/UP	1,275.99	141.78	9.92	2,778.83	9,966.77	1,056.22
SH, MP	2,025.00	225.00	15.75	4,410.00	23,220.00	2,361.83
SH, Uttarakhand	357.83	26.94	2.34	715.65	4,091.10	2,126.82
RR, W. Bengal	24.08	1.28	0.13	61.47	35.60	530.74

kl = kiloliter, km = kilometer, m^3 = cubic meter, mt = metric ton, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Note: The maintenance durations for these sample projects are different because they correspond to their respective operation phase durations. Maintenance usually starts after 3 to 5 years from project construction completion. The maintenance phase duration for NH, MP/UP is 17 years; SH, MP is 27 years; SH, Uttarakhand is 13 years; and RR, W. Bengal is 5 years. Construction materials and fuels used for all maintenance works for the total life period of the NH, MP/UP are less than SH, MP because the maintenance works on NH, MP/UP are estimated for 17 years. The maintenance works on SH, MP are estimated for 27 years meaning that the use of construction materials and fuels is higher for SH, MP. Also, there is some debate over whether a complete resurfacing of the road is regarded as maintenance or reconstruction. This study used data from the executing agencies and contractors based on their own definition of maintenance.

Source: This study, based on information from executing agencies and contractors.

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4 Roads similar in terms of type, width, and traffic characteristics in the same terrain and/or region.

5 The maintenance data collected from the contractors and executing agencies do not segregate between routine and periodic maintenance works. The contractors and executing agencies gave an assurance that these data include all types of maintenance works on the roads, i.e., routine, periodic, or any other.

Table 12. CO_2 Emissions from the Total Maintenance Phase of All Sample Roads

Road Project	CO_2 (ton/km)
NH, MP/UP	11.14
SH, MP	17.66
SH, Uttarakhand	17.73
RR, W. Bengal	2.71

CO_2 = carbon dioxide, km = kilometer, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Note: The CO_2 emissions per kilometer for SH, MP are higher than NH, MP/UP because for SH, MP, the maintenance works are estimated for 27 years while for NH, MP/UP, the maintenance works are estimated for 17 years. This has been done to ensure the maintenance phase corresponds to the respective operation phase duration, i.e., 30 years and 22 years. The SH, Uttarakhand has a maintenance phase duration of 13 years, which is less than NH, MP/UP and SH, MP maintenance phase durations. However, the per-kilometer CO_2 emissions for the maintenance phase are higher than the other two roads because of the high level of maintenance works that would be required for this road through hilly terrain. About 50% of its road length would require significant maintenance works every year due to damage caused by heavy rains and landslides. CO_2 emissions per kilometer are higher even though the maintenance phase duration is shorter compared with NH, MP/UP and SH, MP.

Source: This study.

Total Carbon Footprint

Total carbon footprint for the construction, operation, and maintenance phases of the sample road projects is summarized in Tables 13 and 14 and Figure 2. It can be observed that the road operation phase has the highest contribution to the road's carbon footprint (more than 93% in all sample roads). On the other hand, the road construction and maintenance phases together have a very small share in the total footprint (not more than 7%) of all sample projects.

As stated on page 15, the 2007 report of the Independent Evaluation Department and a handful of project completion reports indicate that the actual traffic on completed roads is often lower than the traffic forecasts used at project appraisal. To understand the change in share of construction and maintenance phase emissions due to change in traffic levels, the results of a sensitivity test as given in Table 10 were used to calculate the possible change in traffic level's effect on CO_2 emissions. It was observed that with changes in traffic (10%–20% increase and decrease), the share of construction and maintenance emissions in the total life cycle emissions of the sample road project ranges between 1.4% and 8.6% as against 1.7% to 7.0% for DPR traffic levels (see appendix). It can therefore be concluded that even if the traffic on sample roads is higher or less than the DPR levels, the construction and maintenance emissions would remain in the range of less than 10% of the total life cycle CO_2 emissions. The remaining emissions (about 90%) occur due to the road operation phase. GHG emissions in the construction and maintenance phases are probably within the margin of error for the projected traffic volumes and kilometers traveled.

Table 13. Total Carbon Footprint of Sample Road Projects

Road Project	Road Length (km)	Time Period (years) A	B	C	CO_2 (ton) A	%	B	%	C	%	Total
NH, MP/UP	128.3	3	22	17	271,380.2	2.8	9,334,322.9	97.2	1,429.2	0.01	9,607,132.4
SH, MP	123.0	2	30	27	46,481.5	1.7	2,763,279.4	98.3	2,172.5	0.08	2,811,933.4
SH, Uttarakhand	40.0	2	16	13	4,382.5	6.0	67,810.6	93.0	709.0	0.97	72,902.1
RR, W. Bengal	5.8	2	10	5	281.0	3.3	8,266.3	96.5	15.7	0.20	8,562.9

A = construction, B = operation, C = maintenance, CO_2 = carbon dioxide, km = kilometer, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Note: The construction phase duration (A) is based on actual date of start and actual and/or expected date completion of roads. The operation phase duration (B) is based on the detailed project report estimation of road life. Maintenance phase duration has been calculated based on the assumption that the maintenance works start 3–5 years after road construction completion and are then continued for the remaining life of the road. From primary surveys of contractors and executing agencies, the maintenance works on NH, MP/UP; SH, MP; SH, Uttarakhand; and RR, W. Bengal is expected to start after 5, 3, 3, and 5 years respectively.

Source: This study.

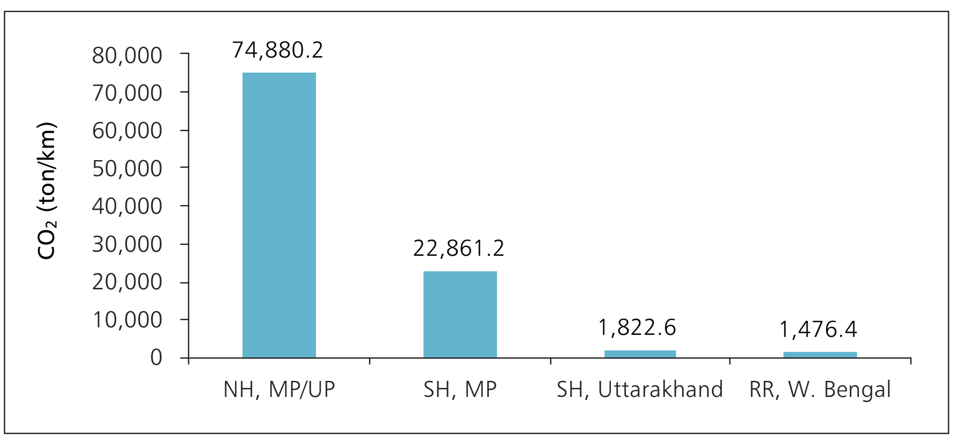
Table 14. Per-Kilometer Carbon Footprint of Sample Road Projects for Their Total Project Life

Road Project	CO_2 (ton/km)
NH, MP/UP	74,880.2
SH, MP	22,861.2
SH, Uttarakhand	1,822.6
RR, W. Bengal	1,476.4

CO_2 = carbon dioxide, km = kilometer, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Source: This study.

Figure 2. Per-Kilometer Carbon Footprint of Sample Road Projects for Their Total Project Life



CO_2 = carbon dioxide, km = kilometer, MP = Madhya Pradesh, NH = national highway, RR = rural road, SH = state highway, UP = Uttar Pradesh.

Source: This study.

Table 15. Total ADB Road Portfolio Carbon Footprint in 2008

Road Type	Road Length (km)	CF in 2008 (million tons)
National highways	1,800.98	5.39
State highways (in flat terrain)	4,562.60	3.26
State highways (in hilly terrain)	1,852.66	0.19
Rural roads	17,354.52	2.13
Total CF of the ADB road portfolio in 2008		10.98

CF = carbon footprint, km = kilometer.

Source: This study.

Carbon Footprint of ADB Road Portfolio in India

The carbon footprint results for the sample projects were used to estimate the carbon footprint of ADB's entire road sector portfolio in India. The total footprint of all ADB-funded road projects in 2008 was 10.98 million tons (Table 15). It may be noted that all these projects may be at different life stages in 2008. Some may be under construction and others under operation. The footprint estimate is an average estimate for 1 year (in this case, 2008) considering the economic life of different types of roads.

Of course, when it comes to influences on climate change, the cumulative emissions from the whole life cycle of the road are more important than the average emissions in 1 year. The results for sample projects were then used to estimate the cumulative CO_2 emissions for all ADB road projects (ongoing and completed) as at 2008 over their design life. The results are given in Table 16.

Table 16. Cumulative GHG Emissions of ADB Road Portfolio (for the total life cycle of all ADB road sector projects, ongoing and completed)

Road Project	Cumulative CO_2 Emissions of ADB Road Portfolio (million tons)
National highways	134.86
State highways (in flat terrain)	104.31
State highways (in hilly terrain)	3.38
Rural roads	25.62
Total CF of the ADB road portfolio as at 2008	268.17

CF = carbon footprint, km = kilometer.

Source: This study.

FINAL NOTES

ADB's South Asia Transport and Communications Division assessed the carbon footprint in road construction and improvement activities in India. The assessment includes developing a comprehensive methodology to estimate the carbon footprint of road projects, collecting relevant data in India to test out the methodology, and analyzing the data to stipulate the total carbon footprint of the South Asia Department's road portfolio in 2008.

The results of the carbon footprint estimations for the sample projects indicated that the emissions from the construction and maintenance phases are relatively insignificant when compared with emissions from vehicular movement on roads for its total life. The future work on carbon footprint estimations for ADB road projects, therefore, may focus on documentation for the operation phase only and avoid the extensive data collection needed for construction and maintenance activities. An allowance of additional emissions of about 5% may be added to operation phase emissions to acknowledge the construction and maintenance phase contributions to the carbon footprint of the road project. This does not mean, however, that efforts to reduce GHG emissions from these phases should be ignored or abandoned.

The study is by no means perfect; the difficulties faced in carrying out this study were the following:

- The data required for the carbon footprint analysis were comprehensive, especially for the construction and maintenance stages of the road projects. Manual data collection from four project sites located in different parts of the country required a lot of effort on the part of the team members.
- Since primary data collected from project sites are vital for the analysis, it was important that local authorities and contractors responsible for road construction projects understand the data needs as envisaged in the framework and questionnaire. Communicating in local languages was hence very important and critical for collecting good quality data.
- The carbon footprint analysis is based on life cycle assessment of carbon impacts of road projects. Conversion factors to estimate carbon emissions specifically embodied carbon values and emission factors are important for accurate calculations. These values are usually not readily available. Much research work needs to be done to select appropriate and context specific values.
- The sample size selected for this study was small because the aim was to demonstrate and check applicability of the designed carbon footprint assessment framework in a short period. Hence, expanding the outputs of small sample size to the total ADB road portfolio in India required a lot of assumptions to be made. This posed as a key challenge.

Further refinements can be made to strengthen the methodology. These may include the following:

- A standard data collection checklist that road contractors and local government authorities can fill at different stages of the road project can be created. This will help reduce the efforts required for data collection and help obtain high quality data, which get updated throughout the life cycle of the project. This kind of data collection method can help ADB periodically monitor the carbon emissions from road projects. This will also help in addressing the issues related to the small sample size used for carbon footprint estimations. If a standard data checklist is created, then all project data can be collected. The estimation done with a total sample will help calculate the real carbon impact of the total ADB road portfolio.
- A standard carbon footprint estimation tool can be developed wherein all the data collected from projects can be fed and the results obtained. The tool could be updated regularly.
- If the carbon footprint share of road construction and maintenance phases is not very high, the same could be removed but after carrying out carbon footprint estimations of a significant number of road projects, which could justify such a decision.

The study can be replicated in other countries, but the following adjustments would be needed:

The carbon footprint tool developed can be easily used in other countries with small modifications, primarily in conversion factors used in the tool:

- Country-specific emission factors, embodied energy, and calorific values should be used.
- Data collection checklists should be modified to suit local contexts; the same could also be translated into local languages if required.
- Based on the additions and/or deletions in the data checklist, the carbon footprint tool could be modified.

As a continuation of the study, the following can be done:

- Further collect data from India or other countries to validate the methodology.
- Undertake another carbon footprint study for the railway portfolio and demonstrate the benefits of a modal shift in terms of reduction in fuel use and emissions.
- Mainstream carbon footprint into project calculation.

The follow-up actions listed above may help ADB reduce its carbon footprint or even make it carbon neutral in its developing member countries, although effective partnership with the governments concerned would be essential. Ultimately, critics of road construction will identify the increased GHG emissions from increasing traffic volumes as a major drawback of ADB's investment portfolio in the road sector. Therefore, it is necessary to stress that an expanded road network not only reduces comparative GHG emissions through smoother travel conditions but also results in significant savings in time, reduced pollutants (other than GHGs), and improved access to markets and services, among other benefits.

Appendix

DATA SOURCES AND REFERENCES FOR EMISSION FACTORS

Emission Factors and Embodied Energy Values

India-specific emission factors and embodied energy values have been used for calculating CO_2 emissions. The sources for these emission factors and embodied energy values include

1. Ministry of Environment and Forests, Government of India. 2004.
   Report on India's Initial National Communication (NATCOM) under the United Nations Framework Convention on Climate Change.

2. Mitra, A.P., et.al. 2004.
   Climate Change and India: Uncertainty Reduction in GHG Inventories
   Universities Press, Hyderabad
   (Book published under the NATCOM project).

3. ARAI. 2007.
   Draft Report on Emission Factor Development for Indian Vehicles, prepared by The Automotive Research Association of India (ARAI), Pune, India.

4. TERI. 2006.
   Energy efficiency and climate change consideration for on-road transportation in India
   New Delhi: The Energy and Resources Institute, 98 pp.
   (TERI Report No. 2005UG27).

5. IPCC. 2006.
   IPCC Guidelines for National Greenhouse Gas Inventories (Volume 2, Energy).

6. Central Electricity Authority, Ministry of Power, Government of India, 2008.
   CO_2 Baseline Database for the Indian Power Sector.

7. Smith, K.R., et.al. 2000.
   Greenhouse gases from small-scale combustion devices in developing countries (Phase IIa): Household Stoves in India.
   Prepared for the US Environmental Protection Agency.

A few emission factors and embodied energy values were not easily available for India. These were derived for the Indian context using a few international studies and/or models as mentioned below:

1. VicRoads, 2008.
   Greenhouse: Carbon footprint of road construction
   Victorian Roads Commission, Melbourne, Australia.

2. Lewis, C.A. 1997.
   Fuel and Energy Production Emission Factors
   MEET Project: Methodologies for Estimating Air Pollutant Emissions from Transport Project funded by the European Commission under the Transport RTD program of the 4th Framework Programme.

Assumptions on Vehicular Technology, Fuel Mix, Fuel Efficiency, and Annual Mileage Changes

In 2006, TERI undertook a study for ADB entitled Energy efficiency and climate change consideration for on-road transportation in India. The study focused on estimating emissions from on-road transportation in India until 2030. The assumptions made in this study with regard to future vehicular technology, fuel mix, and fuel efficiency in India's road sector were used for this study while estimating CO_2 emissions for the road operation phase.

Annual mileage numbers for different modes of transport were based on the following studies:

1. CPCB, 2000.
   Transport Fuel Quality for Year 2005
   Central Pollution Control Board.

2. Kapoor, M. 2002.
   Vision 2020 Transport
   Prepared for the Planning Commission, Government of India.

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Kitzes, J., A. Galli, S.M. Rizk, A. Reed, and M. Wackernagel. 2008. *Guidebook to the National Footprint Accounts.* 2008 Edition. Oakland: Global Footprint Network.

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Otto, M. 2007. *Impact of Growth in Road Transport on the Environment.* United Nations Environment Programme, Division of Technology, Industry and Economics.

Pelkmans, L., E. Verhaeven, G. Spleesters, S. Kumra, and A. Schaerf. 2005. Simulations of fuel consumption and emissions in typical traffic circumstances. SAE transactions, vol. 114, no. 4. (1878 p.) [Document: 7 p.] (3 ref.), pp. 967–973 [7 page(s) (article)]. Society of Automotive Engineers, New York.

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World Bank. 2005. India Country Strategy 2005–2008. Washington, DC.

Methodology for Estimating Carbon Footprint of Road Projects
Case Study: India

Carbon footprint is a tool commonly used to describe the total amount of carbon dioxide and other greenhouse gas emissions for which an individual or organization is responsible. The South Asia Department (SARD) of the Asian Development Bank carried out this study to explore possible approaches and methods to calculate the carbon footprint from its road activities and their total contributions on SARD's overall activities in India.

India was selected for this study because it represents all types of SARD activities (highways, national roads, and rural roads) and the project locations range from urban to rural areas with different ecological conditions. A model of calculating carbon footprint–construction, operation, and maintenance–of road projects was developed, and this model was tested and presented using data from SARD projects in India.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries substantially reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to two-thirds of the world's poor: 1.8 billion people who live on less than $2 a day, with 903 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

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