
The World Bank

Asia Sustainable and
Alternative Energy Program

# Transport

## Greenhouse Gas Emissions Mitigation in Road Construction and Rehabilitation:
## *A Toolkit for Developing Countries*

June 2011

ASTAE



The International Bank for Reconstruction and Development /
The World Bank Group
1818 H Street, NW
Washington, DC 20433, USA



First printing: June 2011
Manufactured in the United States of America.

Photo credits: Egis

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# Acronyms and Abbreviations

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| AAU | Assigned Amount Unit |
| ADEME | Agence de l'Environnement et de la Maîtrise de l'Energie |
| AFD | Agence Française de Développement |
| ASTAE | Asia Sustainable and Alternative Energy Program |
| ATILH | Association Technique de l'Industrie des Liants Hydrauliques |
| BAU | Business As Usual |
| CBR | California Bearing Ratio |
| CDM | Clean Development Mechanism |
| CER | Certified Emission Reduction |
| CRRAP | Cold Recycling of Reclaimed Asphalt Pavement |
| DBST | Double Bituminous Surface Treatment (road) |
| DNA | Designated National Authority |
| EAP | East Asia and Pacific Region |
| EIRR | Economic Internal Rate of Return |
| EMP | Environmental Management Plan |
| EPA | Environmental Protection Agency |
| ERU | Emission Reduction Unit |
| ESA | Equivalent Standard Axles |
| ETS | Emission Trading Scheme |
| EU | European Union |
| FHWA | Federal Highway Administration |
| FIDIC | International Federation of Consulting Engineers |
| FIRR | Financial Internal Rate of Return |
| FUND | Framework for Uncertainty, Negotiation, and Distribution |
| GHG | Greenhouse Gas |
| HMA | Hot Mix Asphalt |
| HMAM | High Modulus Asphalt Material |
| IEA | International Energy Association |
| IRF | International Road Federation |
| IPCC | International Panel on Climate Change |
| IRR | Internal Rate of Return |
| ITL | International Transaction Log |
| JI | Joint Implementation |
| LCPC | Laboratoire Central des Ponts et Chaussées |
| NPV | Net Present Value |
| ODA | Official Development Assistance |
| ORN | Oversea Road Notes |
| PDD | Project Design Document |
| PPD | Perpetual Pavement Design |
| PPM | Parts Per Million |
| QA | Quality Assurance |
| QC | Quality Control |
| RGGI | Regional Greenhouse Gas Initiative |
| SC | Stage Construction |
| SCC | Social Cost of Carbon |
| SETRA | Service D'Etudes Techniques des Routes et Autoroutes |
| TRL | Transport Research Laboratory |
| UNFCC | United Nations Framework Convention on Climate Change |
| WMA | Warm Mix Asphalt |

# Acknowledgments

This publication, which was funded by the Asia Sustainable and Alternative Energy Program (ASTAE), was authored by the consultant Egis International and guided by the direction of Task Team Leader Fei Deng, Senior Transport Specialist, East Asia Sustainable Development Infrastructure Unit at the World Bank. The World Bank team was supported by the efforts of Emily Dubin, Peng Wang, Jean-Marie Braun, and Geoffrey Kurgan. The Egis International team, which was led by Grégoire Nicolle and Nicolas Morice, was supported by the efforts of Matthew Addison, François-Marc Turpin, Marie-Claire Cao, Benoit Ficheroulle, Michaël Nogues, Robert Lynch, Pierre Sarrat, and Agnès Capron. In addition, Egis International was supported by the Egis Environment team, including Mireille Lattuati and Antonin Caen.

During the course of this study, the Egis team gained considerable knowledge through the support of a number of different agencies and organizations in China, Indonesia, and Vietnam. In particular, the team would like to acknowledge Shandong Luquiao Group Co. Ltd., Hebei Provincial Communications Dept., and the Chinese Metallurgy Civil Engineering Corp. in China. In Indonesia, the team is indebted to the assistance of the Australian Agency for International Development (AusAID), the Ministry of Public Works, and the Directorate General of Highways. Finally, in Vietnam, substantial support was provided by the Asian Development Bank (ADB), the Vietnam Expressway Corporation, and Transport Engineering Design Inc. (TEDI). Both the Bank and the Egis teams gratefully recognize the time and insight provided by these partners—for without them, this project could not have become a reality.

The teams would like to give special recognition to World Bank staff for their help with the peer review process and for providing considerable feedback including: Cesar Queiroz (INTSC), Federico Querio (ENV), Sameer Akbar (ENV), Nat Pinnoi (ENVCF), and Peter O'Neill (TWITR). In addition, the teams would like to gratefully acknowledge the valuable comments that were received during the software review process by Mauricio Ruiz from The Transtec Group, Dr. Richard Jon Porter at the University of Utah, Milena Breisinger from the Inter American Development Bank, Patrice Danzanvilliers at the French Ministry of Transport, as well as Jonathan Slason and Simon Bannock from Beca.

The Bank team would also like to give thanks to Steve Meltzer for editing the document, Laura Johnson for providing the graphic design work, Marti Betz for the work on the cover design, and Laurent Durix for his effective coordination in the publication and dissemination of this report.

Throughout this study, the Bank team enjoyed the encouragement provided by many colleagues; in particular the team would like to recognize the strong support and guidance from Vijay Jagannathan (EASIN) and Ede Ijjasz (EASCS). Finally, the teams would like to acknowledge ASTAE for their vision in funding a multisectoral project such as this. The achievement of adopting renewable energy sources, improving energy efficiency, and increasing access to energy cannot be truly accomplished without all sectors working together. This study is a significant step in proving that a multisectoral approach to the ASTAE objectives can be realized.

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# Introduction

## 1.1 Context and Background

### 1.1.1. Context

The goal of the transport sector of the World Bank's East Asia and Pacific Region (EAP) is to identify solutions that minimize greenhouse gas (GHG) emissions caused by road construction and rehabilitation in the region. The transport team was awarded a grant from the Asia Sustainable and Alternative Energy Program (ASTAE) to finance creation of a toolkit addressing GHG emissions resulting from such development and restoration activities.

It is anticipated that over the next several years, developing countries in East Asia will substantially expand and restore their extensive road networks. One result of these activities will be increased GHG emissions. Reducing these could significantly decrease the negative impacts related to these infrastructure works.

There are several steps involved in road construction that contribute to the production and release of GHG emissions: site clearing, subgrade preparation, production of construction materials (granular sub-base, base course, surfacing), site delivery, construction works, ongoing supervision, maintenance activities, and so on. The aggregate GHG emissions for each project or sub-project (phase, section, alignment) can be calculated based on equipment used, local conditions, and standard construction and maintenance practices.

This document has been prepared as part of a study aimed at identifying and quantifying the GHG emissions from current practices, and at developing a strategy for better planning, design, and construction of roads. It is meant to give planners, designers, and contractors a tool with which they can explicitly compare emissions and costs, as well as make more informed decisions—some of which will result in lower-emission roads.

### 1.1.2. Purpose of the Toolkit

The Greenhouse Gas Emission Mitigation Toolkit for Highway Construction and Rehabilitation (ROADEO), together with the accompanying User Manual (see appendix B on the accompanying CD) will guide road practitioners through the various stages and activities of road construction and rehabilitation, help them identify areas sensitive to GHG emissions, and present various mitigation options that take cost and benefit implications into account. With the ROADEO calculator, decision makers, designers, and technicians in the highway sector can easily compare various construction alternatives and optimize their practices to both minimize GHG emissions and maximize energy efficiency. It is envisioned that the ROADEO calculator will be used on both new and existing projects. The toolkit includes:

- A set of reports providing background information on GHG emissions from road construction activities
- A calculator tool, ROADEO (ROADs Emissions Optimisation)
- The ROADEO calculator user manual

### 1.1.3. Approach Followed to Develop the ROADEO Calculator

The preparation of the ROADEO calculator involved nine activities.

- Task 1: Undertake a broad assessment of GHG emissions related to the transport sector
- Task 2: Complete a detailed literature review on GHG emissions from road construction and rehabilitation activities
- Task 3: Review current road construction and rehabilitation practices in three East Asian developing countries
- Task 4: Select recent case studies, with detailed analysis of GHG emissions, in each country
- Task 5: Perform GHG emissions calculations
- Task 6: Identify gaps between best practices in developed countries and practices in pilot developing countries and propose alternative practices that could represent improvements
- Task 7: Assess costs and benefits of each alternative practice proposed in Task 6
- Task 8: Develop the Greenhouse Gas Emission Mitigation Toolkit for Road Construction and Rehabilitation
- Task 9: Complete the User Manual to accompany the ROADEO calculator

## 1.2. Purpose of this Background Report

The purpose of this background report is to present the findings of the study that led to the development of the Toolkit. It is intended to introduce nonspecialists to the main issues involved in road construction-related GHG emissions in East Asia. While it was not possible to investigate all details, or to cover the very wide range of situations met on all road projects, efforts were made to identify orders of magnitude, extents and impacts, as well as converging and diverging practices in the road community on some topics.

It is hoped that the report will provide users with useful, detailed information gathered during the preparation of the Toolkit.

This document does not fully describe the functions of the ROADEO calculator; that is the purpose of the User Manual, which can be found in the CD that accompanies this report. Reference can be made to this background report.

## 1.3. Structure of this Background Report

This background report includes:

- Main body (this document) provides general information and an executive summary of the document's content.
- Annexes, each covering an aspect of GHG emissions as they relate to road construction and rehabilitation. Due to the extensive volume of material covered through this study, the annexes have been placed in the CD that accompanies this report.
  - Annex 1—Introduction to GHG emissions from road construction
  - Annex 2—Review of current road construction practices in East Asia
  - Annex 3—Lower-emissions alternative practices for road construction
  - Annex 4—Economic and financial analysis of road construction GHG emissions

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# General Analysis of Road Construction Emissions

## 2.1. GHG Emissions in Road Construction

### 2.1.1. Road Transport GHG Emissions Globally and by Region

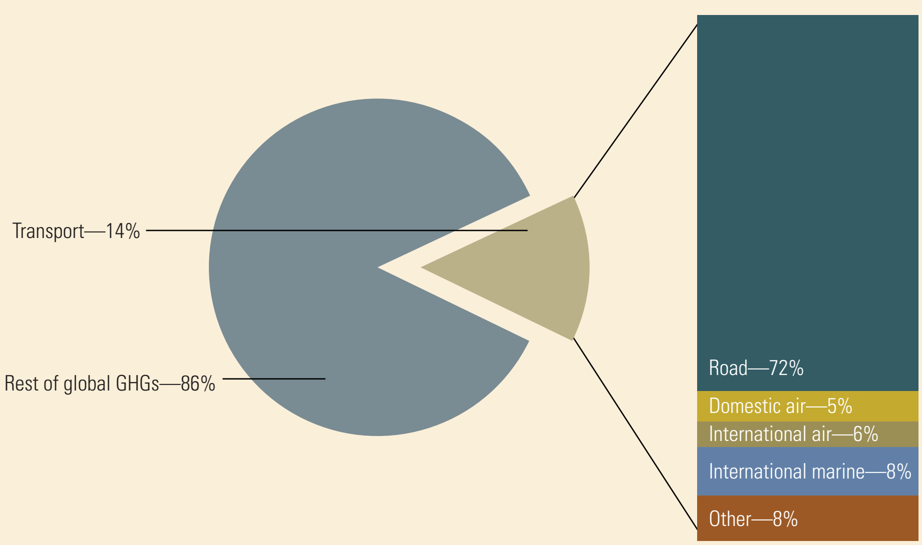
A 2005 International Energy Association (IEA) study revealed that the transport sector (road vehicles, trains, ships, and aircraft) is the second largest producer of GHG emissions. Road transport accounts for about 90 to 95 percent of the sector's production (figure 1).

Table 1 (next page) shows that road transport in Asia is a major contributor to transport GHG emissions. This is the region of the world currently constructing the most new roads, and represented 37 percent of man-made GHG emissions in 2005.

### 2.1.2. Rationale for Focusing on Road Construction Activities

- While road construction GHG emissions represent only 5–10 percent of total GHG emissions in the sector, they are growing rapidly, especially in Asia, the result of the region's major ongoing road programs in support of economic development.
- Road construction mitigation efforts are relatively easy to manage, and can have higher-profile impact

**FIGURE 1 ROAD TRANSPORT EMISSIONS AS PART OF GLOBAL AND TRANSPORT GHG EMISSIONS**




*Source:* EIA, 2004.

**TABLE 1 REGIONAL BREAKDOWN OF ROAD TRANSPORT SHARE IN TRANSPORT GHG EMISSIONS**

| | GHG emissions in 2005 (Mt eq$CO_2$ and %) | | | Road transport contribution to transport sector |
|---|---|---|---|---|
| | Total | Transport sector | | |
| World | 38,725.90 | 5,378.00 | 14% | 72% |
| Asia | 14,236.90 | 1,098.80 | 8% | 95 to 100% |
| Europe | 8,141.90 | 1,244.10 | 15% | 93% |
| North America | 7,834.00 | 1,973.60 | 25% | 85% |
| Central America and Caribbean | 773.60 | 161.1 | 21% | n.a. |
| Middle East and N. Africa | 2,566.90 | 388.9 | 15% | n.a. |
| South Africa | 2,124.90 | 286.9 | 14% | more than 50% |
| Sub-Saharan Africa | 1,083.20 | 104.2 | 10% | n.a. |
| Oceania | 647.20 | 93.7 | 14% | 84% |

*Sources:* WRI, ADB, EEA, EPA and National Inventories.

(of interest to international financial institutions [IFI] like the World Bank) than actions on road traffic.

- Most road agencies in Asia are not yet aware of the impact of their activities on GHG emissions, even though Asia is at the center of current road construction efforts. It is important to raise stakeholders' awareness to improve current practices and to facilitate more informed decision making.

## 2.2. Main Issues

An assessment of road construction GHG emissions was performed on "typical" road sections of various types or categories. In the absence of order of magnitude of various issues, this was expected to provide an indication of:

- the respective importance of various parts of the road network in GHG emissions, through a comparison of construction emissions of various categories of roads with different characteristics (geometry, pavement, structures, and so on) and ranging from expressways to unpaved rural roads, and
- the emissions contributions of various components of the project, from pavement to structures, earthworks, road furniture (such as guardrails, lighting, signs, barrier walls, and the like) and drainage.

The calculations were made on simplified assumptions, and were performed with the "CHANGER" tool developed by the International Road Federation (IRF).

### 2.2.1. Global Emissions

The total GHG emissions for the construction of a 1 km section of each type of road are shown in table 2.

We see that the construction of 1 km of expressway emits as many tons of $CO_2$ as 4 km of national roads, 15 km of provincial roads, and around 33 km of rural roads.

### 2.2.2. Emissions Per Work Item and Per Type of Road

Figure 2 shows emissions produced by (i) extraction/production of construction materials, (ii) their transport, and (iii) consumption by engines used for placing them.

Structures and road furniture represent almost 50 percent (46.4 percent) of the emissions from construction of an expressway. Choices that can limit these emissions are thus of paramount importance.

For national roads, safety barriers alone represent one-quarter of the total emissions during construction. Changes in practices regarding these items would have a very significant impact on the project's final footprint.

For all the other roads, pavement is the major GHG producer. The main parameters to be considered, as presented in table 4, relate to transport emissions (distance to the concrete factory, distance to the quarry/borrow pit, and so on).

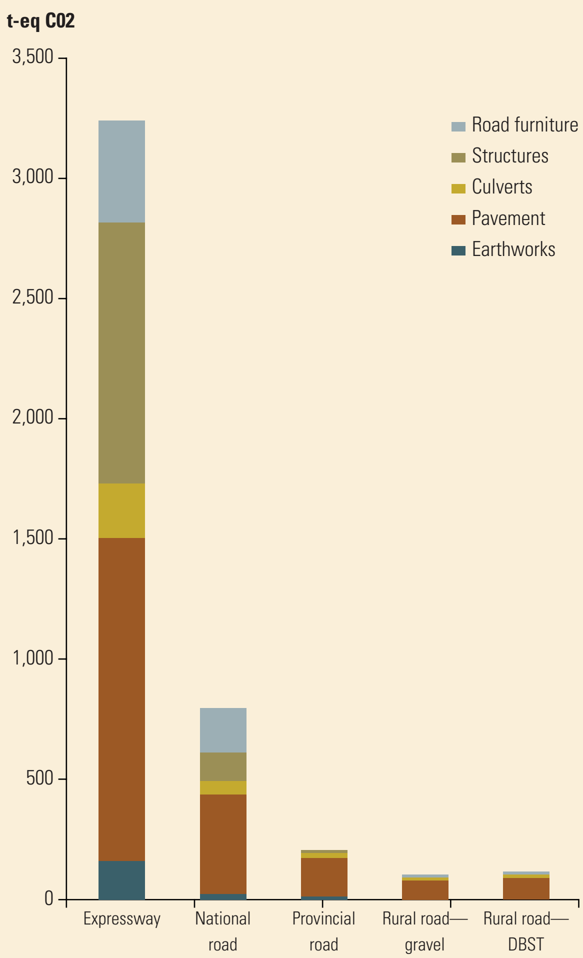
**TABLE 2 TYPICAL UNIT GHG EMISSIONS OF VARIOUS ROAD CATEGORIES (t $CO_2$ eq./km)**

| | Expressway | National road | Provincial road | Rural road—gravel | Rural road—DBST |
|---|---|---|---|---|---|
| Emission (t $CO_2$ eq./km) | 3,234 | 794 | 207 | 90 | 103 |
| Factor equivalent to Expressway | 100 | 24.5 | 6.4 | 2.8 | 3.2 |

*Source:* EIA, 2004.

*Note:* Expressway: Divided highway used by high-speed traffic with controlled or partially controlled access; National road: Generally funded, constructed, and operated under the auspices of the national government or, more specifically, the Ministry of Transport (usually these roads have lower traffic and weight demands compared to expressways); Provincial road: Generally funded, constructed, and operated under the auspices of the provincial government (usually have lower speeds, weight classes, and traffic demands compared to a national road); Rural gravel road: Constructed with only a gravel wearing course and operated under the auspices of a local government authority within the provincial government or a separate agency such as a department of feeder roads (usually these roads have unlimited access, are unmarked, and have low traffic demands); Rural DBST road: Double bituminous surface treatment road, generally a major feeder road found in rural areas that falls under the same auspices as the authority or department that oversees rural gravel roads (usually higher quality than rural gravel roads because of their higher traffic and weight requirements).

**FIGURE 2 EMISSIONS PER ITEM OF WORK, BY TYPE OF ROAD**



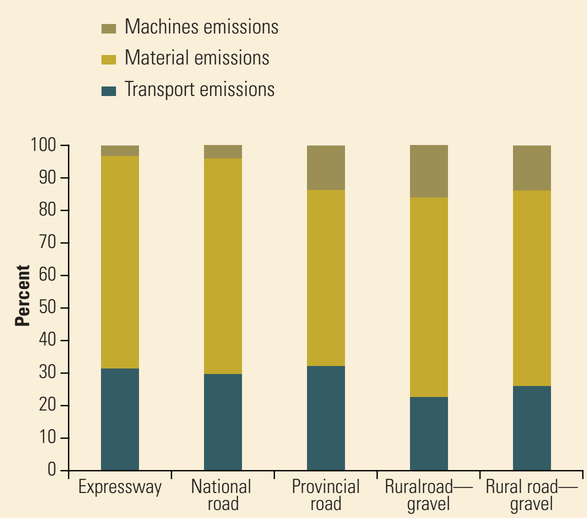

*Source:* Egis, 2010.

### 2.2.3. Emissions Per Phase of Work and Per Type of Road

For expressways and national roads, GHG emissions from the fabrication and extraction of construction materials are the main contributor, at about 90 percent of total emissions; they are less important for provincial and rural roads, at about 80 percent.

Materials transport is also a significant GHG producer, at around 25 percent for expressways and national roads and up to 20 percent for provincial and rural roads.

**FIGURE 3 EMISSIONS PER GHG GENERATOR, BY TYPE OF ROAD**




*Source:* Egis, 2010.

**TABLE 3 TYPICAL BREAKDOWN OF GHG EMISSIONS, BY WORK ITEM, FOR VARIOUS ROAD CATEGORIES (t $CO_2$ eq./km)**

| Emissions (t $CO_2$eq./km) | Expressway | National road | Provincial road | Rural road—gravel | Rural road—DBST |
|---|---|---|---|---|---|
| Earthworks | 161 | 16 | 12 | 3 | 3 |
| Pavement | 1,334 | 425 | 157 | 72 | 86 |
| Culverts | 238 | 51 | 17 | 12 | 12 |
| Structures | 1,068 | 119 | 21 | 3 | 3 |
| Road Furniture | 432 | 182 | 0 | 0 | 0 |
| Total | 3,234 | 794 | 207 | 90 | 103 |

*Source:* Egis, 2010.

**TABLE 4 TYPICAL BREAKDOWN OF GHG EMISSIONS, BY GENERATOR, FOR VARIOUS ROAD CATEGORIES (t $CO_2$ eq./km)**

| Emissions (t $CO_2$eq.) | Transport emissions | Material emissions | Machines emissions | Total |
|---|---|---|---|---|
| Expressway | 1,004 | 2,122 | 109 | 3,234 |
| National Road | 235 | 523 | 36 | 794 |
| Provincial Road | 66 | 112 | 29 | 207 |
| Rural Road—Gravel | 20 | 56 | 14 | 90 |
| Rural Road—DBST | 26 | 62 | 14 | 103 |

*Source:* Egis, 2010.

Extraction and material transport are therefore the main activities that must be considered to significantly improve the GHG impact of a road construction project.

## 2.3. Current Road Design and Construction Practices in East Asia

Three East Asian countries were designated for data collection by this study—China, Indonesia, and Vietnam. These pilot countries were selected because of the size and potential of their highway sector development activities.

Information was collected on:

- road development, particularly of current road networks, highway master plans, ongoing road projects, and past and future expenditures for road construction or rehabilitation, and
- current practices, particularly contract packaging, implementation techniques, design methodologies, capacity of national contractors, and technical specifications in road construction or rehabilitation contracts.

The analysis carried out on GHG emissions for typical road sections shows that the construction of expressways would generate far more GHG per kilometer than construction of other road categories. Pavement (only flexible pavement was considered in this analysis) would generally be the major GHG emissions source, but the share of GHG emissions from structures is quite significant as well, as is the share of metallic rails for national roads.

Applying this analysis to selected countries shows that possibilities for reducing GHG emissions may significantly vary depending on current road length, distribution of road networks by type, and their assumed extension in the coming years.

### 2.3.1. Standards

In general, road authorities in East Asian countries have heavily referenced American Association of State Highway and Transportation Officials (AASHTO) standards

**TABLE 5 ORDERS OF MAGNITUDE OF GHG EMISSIONS RELATED TO THE ROAD CONSTRUCTION PROGRAM IN THREE EAST ASIAN COUNTRIES, 2009–19**

| | Indonesia | | Vietnam | | China | |
|---|---|---|---|---|---|---|
| $CO_2$ emissions (t eq $CO_2$) | 2009–19 | 2009–19 | 2008–20 | 2008–20 | 2008–20 | 2008–20 |
| Expressway | 6,054,048 | 20% | 13,696,941 | 54% | 79,873,000 | 25% |
| National Road | 11,706,139 | 39% | 5,848,337 | 23% | 115,683,000 | 37% |
| Provincial Road | 4,992,098 | 17% | 2,208,218 | 9% | 54,169,000 | 17% |
| Rural Road—Paved | 7,189,451 | 24% | 3,708,669 | 15% | 63,983,000 | 20% |
| Total | 29,941,737 | | 25,462,165 | | 313,708,000 | |

*Source:* Egis, 2010.

when developing their own standards. China and Vietnam have adapted them to fit the specific conditions of the country. Indonesia has developed a set of regulations and standards partly based on AASHTO. In some cases, the AASHTO standards coexist with others (Vietnam also uses some Russian standards).

### 2.3.2. Geometric Designs

Asian countries face a number of obstacles regarding geometric design, which deals with the portioning of the physical elements of the roadway according to standards and constraints. These are related to land acquisition, use or quality of traffic growth data, project funding, and development strategies of local or national governments. Individually or in combination, this may lead to inappropriate road designs and ultimately to traffic congestion well before the road has reached its design age, which is typically understood to be the age that the road is expected to reach before major reconstruction is necessary due to an increase in traffic demands or natural deterioration.

### 2.3.3. Pavement Design

Asian countries tend to adopt a policy promoting short design life (about 10 years) to save on construction costs and because of the uncertainty connected with predicting long-term traffic volumes. However, initial cost savings under this strategy are often offset by mid-term and overall life-cycle costs required for maintenance and rehabilitation, which may result in increased GHG emissions.

Though vehicle overloading is a major issue in Asia, it has rarely been taken into account at the design stage. This has commonly resulted in premature end of pavement life. Overloaded vehicles adversely and significantly affect GHG emissions, not only because they decrease road serviceability life, but also because of resulting increases in maintenance costs, vehicle operating costs, and road safety.

Finally, the lack of appropriate maintenance planning and optimization keeps the level of service of highway

**Four-Lane Expressway in Yunnan Province, China with Emergency Lane, Concrete Shoulders, and Concrete/Metallic Guardrail**

**Pavement Surface Fatigue on Provincial Road in Indonesia**

**Modern Asphalt Plant on BaoLong Expressway in Yunnan Province, China**

operation below the required standard, leading to an extensive increase in emissions by road users, and the need to reconstruct rather than maintain or rehabilitate pavements.

### 2.3.4. Structural Design

A wide range of structural design methods and types of structure are currently under construction in East Asia. In China, arch, cable-stayed, prestressed concrete, and suspension bridges are being designed and constructed in large numbers, and low-carbon and environmental considerations are being practiced among bridge practitioners, as well. In an attempt to reduce $CO_2$ emissions, structure optimization in bridge design is usually pursued by reducing materials usage.

Vietnamese structural design standards are based on American specifications. Until recently, most bridges there were designed with limited span lengths (less than 40m), using basic reinforced concrete designs. Prestressed concrete and metallic and composite structures have not been widely used thus far, but have been gradually introduced.

**Old Paver in Use on NH26 Rehabilitation Project in Vietnam**

**High Labor Intensity in Surface Dressing on County Road in Hubei Province, China**

Indonesian standards (other than the Indonesian Reinforced Concrete Code) refer directly to AASHTO standards. Australian practices also have heavily influenced structural design; since the 1980s, several Australian firms have built and erected pre-cast concrete bridges. Transfield metallic prefabricated bridges (either truss or girder) are also very common. In addition, various internationally funded programs have supported the use of truss and girder metallic bridges, which are now built by local firms. In recent projects, integral abutment bridges, which take into account seismic action in a relatively sophisticated way, are being used.

### 2.3.5. Project Management

Management of road projects in Asia is generally complex, the result of inadequate control of implementation activities by project owners. The most common problems and issues are (i) delays in decision making by public authorities (often related to gaining approval or consensus from various agencies), and (ii) insistence on decisions and solutions that are not always based solely on sound engineering considerations. In many cases, this is a result of the project owner's representatives lacking adequate engineering training and experience.

Delegation of main project implementation responsibilities to the engineer, as understood under International Federation of Consulting Engineers (FIDIC) designation, to the design-build or engineering, procurement, and construction contractors, or both, could greatly expedite the implementation process, while responsibility for major decisions (such as critical design, specification changes, and large variation and change order approvals) could still be retained by project owners.

Asphalt Mixing Plant Producing in Poor Conditions in Vietnam

Modern Asphalt Plant near Hanoi, Vietnam

### 2.3.6. Contractors

The capacity of contractors on road projects in East Asia varies widely, depending on the type of road, the location and size of the project, and the level of international contractors' involvement. This section provides a brief synopsis of the capabilities and equipment used by local contractors in East Asia, as well as a short overview of international contractor involvement in the pilot countries.

For large projects in Asia, most contractors and expressway companies use the latest generation of equipment for activities such as asphalt production and implementation on site with graders, asphalt finishers, and compactors. Contractor laboratories also benefit from modern devices that can meet international best practices for mixture design of asphalt and other road-works materials.

In Vietnam, very few private contractors have their own equipment; many of them hire subcontractors with specialized equipment for major tasks such as supplying aggregates, production of hot mixtures, and construction of small bridges and culverts. As subcontractors are independent and often engaged in more than one job at a time, follow-up quality control becomes extremely difficult to provide.

In all Asian countries, for smaller provincial and rural road construction or rehabilitation projects, projects are often managed by the local government (county or village, for example), so large work crews are common and motorized equipment is not. Asphalt production in most cases takes place under poor conditions, even in some modern asphalt plants.

For these smaller projects, the results obtained from laboratory tests are often inaccurate, because laboratory staff is insufficiently skilled and compliance with testing standards and procedures is inconsistent. Contractors generally have little capacity for road design, testing, mixture designs, and construction operations. The result is low quality and unexpected delays in the construction stage of various projects.

Private contractors in Indonesia often suffer the same difficulties as Vietnam in meeting good standards. Very few local contractors have the competencies necessary to construct rigid pavements or concrete structures. These types of contracts usually remain in the hands of international contractors. Heavy equipment and other work requiring skilled operators are required to achieve results expected by the international standards that often must be met, but very few Indonesian contractors have or lease heavy equipment.

Since China joined the World Trade Organization, more foreign contractors have attempted to enter the Chinese construction market. The strict legal framework regulating their activities requires all foreign contractors to associate with a local contractor to perform road work. Though the Ministry of Construction's Decree 32 relaxed some restrictions, enough remain in place that the market share of foreign contractors has never exceeded 6 percent.

In Vietnam and Indonesia, foreign contractors (mainly Japanese, Chinese, or Korean), participate in international packages, as they generally have adequate financial resources, significant experience, and efficient management practices. However, these advantages are at least partially offset by equipment costs, travel and housing expenses, and manpower procurement. In view of this, simple tasks (excavation and drainage, for example) are commonly subcontracted to local contractors. This practice is systemic in Indonesia.

### 2.3.7. Quality Assurance and Quality Control

Road construction quality is based on: (i) Quality Assurance (QA)—assurances that all aspects of the facilities, procedures (sampling, testing and storage), and personnel are appropriate, and (ii) Quality Control (QC)——tests carried out in accordance with the appropriate specifications. For the purposes of this report, "Quality Assurance" is used to denote both QA and QC unless noted otherwise.

Some of the most common road construction Quality Assurance problems and issues across all developing Asian countries follow.

- Aggregate and soil sampling:
  - Failure to take all required samples;
  - Individual sample volumes too small for repeat tests (if required) and storage;
  - Sampling not adequately supervised by an engineer;
  - Samples and/or sampling locations not properly identified or recorded;
  - Failure to protect samples from moisture, sample bag holes, and the like; and
  - Samples taken not representative because of accidental or purposeful selection of atypical samples (at the base of aggregate stockpiles, for example, rather than within the stockpile itself).
- Asphaltic cement and concrete sampling:
  - Samples not taken or tested at the plant or (for concrete) taken from the first rather than subsequent output;
  - Incorrect marking and temporary storage of concrete samples on site; and
  - Failure to test materials throughout the day and near the end of a placement.
- Sample preparation:
  - Incorrect sample preparation; and
  - Inadequate mixing of samples.
- Testing procedures:
  - Wrong procedure;
  - Incorrect edition of testing procedure; and
  - Lack of close technician supervision of the required testing procedure.
- Testing equipment:
  - Antiquated and damaged equipment;
  - Lack of spare parts; and
  - Malfunctioning equipment.
- Testing implementation:
  - Testing at the wrong (nonstandard) temperature (difficult in hot countries to maintain 20 degrees Celsius);
  - Samples compacted on non-rigid floors or benches; and
  - Instruments or dial gauges read incorrectly.

In China, contractors are strictly controlled by the government. All bids require adequate qualification certificates for contractors, for design institutes, and for laboratories. The preparation of an approved Quality Assurance plan is mandatory. In Indonesia and Vietnam, the Quality Assurance approach is still in its early stages. Insufficient QA results in lower road-life duration and in some cases requires more materials to be used.

### 2.3.8. Environmental Management

All countries studied in East Asia now require and include an Environmental Management Plan (EMP) before beginning any major construction project. Table 6 shows the agencies responsible for implementing and monitoring an EMP.

**TABLE 6 ROLES IN ENVIRONMENTAL MANAGEMENT**

| | China | Vietnam | Indonesia |
|---|---|---|---|
| Governing Institution | Ministry of Environmental Protection | Vietnam Environment Authority, MoNRE | Ministry of Environment |
| Implementation Unit | Project-specific Environmental Management Office (EMO) | National Environment Agency | Environmental Management Agency |

There are a number of environment-related deficiencies in construction implementation in the pilot countries. The two below are commonly reported.

- Generic or generalized mitigation measures, that is, mitigation measures that are too general ("minimize erosion/dust/runoff," for example). These make some mitigation measures impossible for the contractor to implement and the engineer to control—and leads to disagreements among environmentalists, engineers, owners, and contractors. At best, only extreme issues and inadequate compromises can be realistically achieved. This situation can be remedied, at least in part, by (i) adopting criteria presently in place in developed countries to ensure that mitigation measures or requirements are realistic and quantifiable; (ii) adding relevant, appropriately developed requirements in the Conditions of Contract; and (iii) adding, where possible and relevant, unit prices for the mitigation activities to be carried out.
- Priority sensitive issues not agreed at the highest level. In one not atypical instance, a decision was made at a high level (Ministry of Environment)—but not at the highest level (Governor)—to restrict the right-of-way in a forest reserve, resulting in inadequate width for road and drainage. The Governor of the affected province subsequently gave a direct order to the contractor to clear the width of trees to provide for minimum standards—with the outcome that additional trees were unnecessarily cut down and the EMP was not followed as intended.

### 2.3.9. Construction Practices

#### 2.3.9.1. Earthworks

There are several general earthwork design and construction issues that adversely affect GHG emissions in all Asian developing countries, including:

- use of high fills in flood-prone areas,
- adoption of steep side-slopes with inadequate slope protection, and
- use of inappropriate equipment and construction techniques.

These general issues are discussed in annex 2 on the CD; and specific issues (including identification of countries in which the issues are acute) are detailed in the subsequent subsections of the annex for the individual countries studied.

#### 2.3.9.2. Drainage

Road drainage problems dominate in the pilot countries, the result of high rainfall, flooding and damage to road facilities, and governments' insufficient awareness of the range of detrimental effects of inadequate or inappropriate measures. Drainage structures are expensive (a major consideration during the design stage), but the resulting high maintenance costs (and the reduced traffic efficiency during maintenance operations) attributable to lack of adequate drainage is even more costly. The additional GHG emissions attributable to congestion and other side-effects of maintenance operations are significant.

#### 2.3.9.3. Pavement

Some of the more common pavement-related GHG emissions problems in Asia follow.

- Low pavement quality;
- Inadequate pavement design, often the result of inadequate traffic background studies or projections or of failure to consider the impact of overloaded vehicles;
- Use of materials and quarries that contain relatively soft (generally sedimentary) aggregate particles, lack of adequate quality control, particularly in provision of true crusher dust instead of clayey, silty fines and fine sand (from lack of crusher pre-screening); and
- Failure to adjust laboratory asphaltic mixture designs for actual hot bin materials and/or making subsequent adjustments to the job mixture formula as the materials undergo change; and
- Premature pavement failure, requiring early and more frequent maintenance.
- Poor pavement maintenance:
    - Frequent delays in pavement maintenance because of constraints on budget amounts and availability;

Concrete Drainage Ditch in Urban Area In Vietnam

- Delay of pavement maintenance until the end of the rainy seasons; and
- Maintenance or repair of pavement failures often conducted by only replacing the asphaltic surface layers rather than the more often substandard subgrade and gravel layers below the asphaltic surface.

The additional pavement work caused by these problems and the delays in traffic during as work is carried out have an adverse effect GHG emissions.

#### 2.3.9.4. Structures

Structures for roadway projects in Asia are generally of a higher standard than the connecting road sections. Specific structure issues in the three selected countries are presented in annex 2 on the CD.

In all Asian developing countries, one of the main opportunities for GHG emissions reductions is increased use of precast prestressed concrete bridges rather than the typical composite construction bridges. This can effect significant reductions in materials costs (concrete and steel) and in construction (erection) time. It can also reduce delays in concrete placement during the wet season, and disruption of both public and construction traffic.

#### 2.3.9.5. Road furniture

There are several road furniture types and levels of effectiveness in the East Asian pilot countries. In China, slip forms are commonly used for concrete barriers. A mix of metallic crash barriers and concrete crash barriers is used on many expressways, in the median and/or on the shoulders. Concrete crash barriers are very common on bridges. Although these are intended to protect the motoring public, metallic or concrete crash barriers are often not properly installed.

In Indonesia and Vietnam, there has been very limited use of slipform for concrete barriers. Their use may increase as future expressway projects (the first) are completed. On highways, safety barriers are not constructed to international standards (concrete posts with metal guardrails), and often are poorly maintained, resulting in severe damage to vehicles in accidents, and adverse safety issues for users or local inhabitants behind the barriers.

#### 2.3.9.6. Maintenance

Maintenance is typically not sufficiently integrated into planning scenarios in Asian countries. There is a significant lack of comprehensive, reliable, and updated road data, which would give road authorities a clear picture

Paving of Binder Course on National Road in Vietnam

of the conditions of their respective networks—essential in planning routine and corrective maintenance and corresponding funding. There is also a lack of experienced input on optimum maintenance scenarios, and decisions do not take advantage of experience gained on implemented projects. Perhaps the main problems with maintenance are the result of inadequate or absent "soft" skills rather than engineering skills such as lack of managerial capacity, poor information and data management, institutional weaknesses.

Routine maintenance is generally under the control of local authorities, although the budget may be provided by the central government. Any delay in the appropriation of national funds to local authorities—and in subsequent planning and performing maintenance works—commonly results in routine maintenance issues becoming more acute and therefore more suitable for periodic maintenance.

Expressway with a Mix of Concrete Crash Barriers in the Median Reservation and Metallic Crash Barriers on the Shoulders in China

**High-Capacity Deflectometer for Deflection Measurements and Pavement Structural Assessment in Hebei Province, China**


**Routine Maintenance Work on a Rural Road in Indonesia**

Attempts to use late-arriving routine maintenance funds to resolve these now acute defects result in substandard repair or proper repair of only some defects. In many cases, lack of experience results in maintenance not being carried out on a priority basis.

Periodic maintenance programs are generally carried out by the central government, often using international funding. Delays similar to those noted above have the same result: identified periodic maintenance works that are delayed may require reconstruction by the time funding is received and contractors are selected.

In some cases, slight delays can disrupt an entire program, as works not completed before the onset of the wet season may not receive maintenance under the program—and in many cases may be completely destroyed during the wet season.

#### 2.3.9.7. Work zone traffic management

GHG emissions from vehicle operation are extremely high; minimizing delays and other constraints to traffic operation during construction and subsequent maintenance therefore represents a significant emissions-reduction opportunity.

Road improvement projects in Asia typically do not begin until the road is approaching capacity. This causes traffic management problems and constraints—and associated GHG emissions— to be far greater than if work had begun before capacity became critical. This is also commonly true for new road projects, as maintaining alternate roads is generally given a low priority; authorities often prioritize completing the new road over maintaining the current one.

Road project implementation time in some Asian countries is relatively long because using small packages allows a number of small contractors to participate. This means that there are delays for each package within the project; fewer delay points are common when one large contractor is used. The longer the implementation period, the longer traffic is subject to road closures, delays (section closures), and lower operating speeds. Increasing the capacity of local contractors or utilizing larger and more experienced local or foreign contractors could reduce implementation time.

The reduced actual road life typical in Asia means that traffic operation constraints (and therefore GHG emissions) over a particular period are greatly increased. The constraints for 20-year design roads that last only 10 years are double those for roads that achieve actual design life.

Traffic operations delays in Asia are generally far less a matter of concern than in developed countries, resulting in simplistic traffic management plans that are (generally) advantageous to the contractor. Improved traffic management planning, and the creation of government guidelines establishing maximum delay points and delay periods, would together reduce delays— while motivating contractors to be more proactive in minimizing delays. This could be achieved in part by guidelines, for example, requiring all significant road closures to be at night, during off-peak hours, or on days with the least traffic).

Generally, the relatively low quality of road works in Asia (particularly pavement works) requires that there be more maintenance work and therefore more interruptions to normal traffic operation. These can be minimized by (i) improved pavement construction quality, (ii) use of materials and construction procedures that minimize the time required to perform works, and (iii) scheduling maintenance works at off-peak periods as noted above.

3

# Development of a Calculation Tool

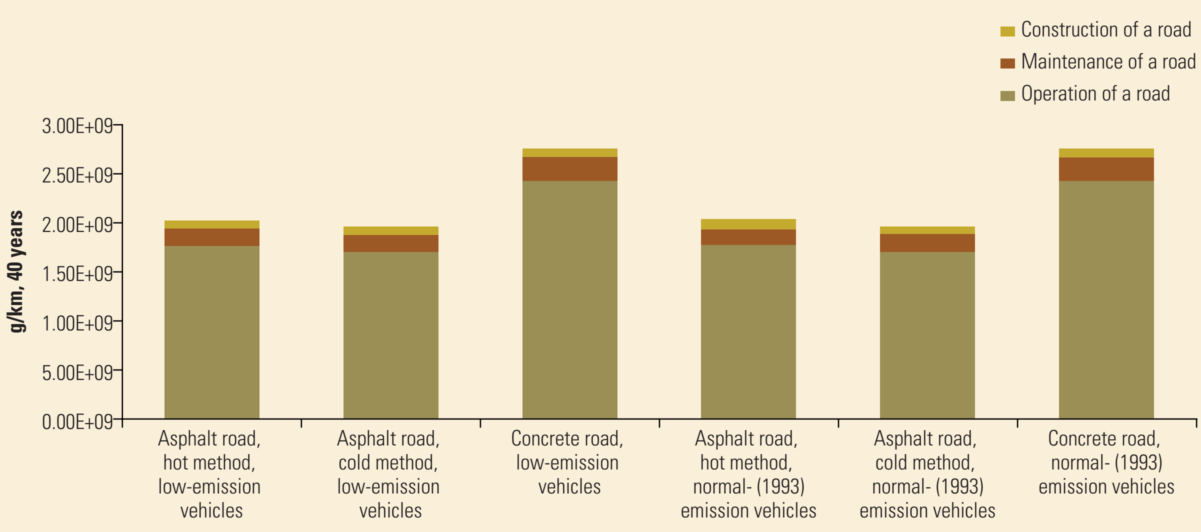
## 3.1. Need for Tools

Concern about climate change and greenhouse gas emissions has prompted action in most sectors and spurred the development of decision tools that help make choices transparent and illuminate their contribution to GHGs. Transport is no exception.

Early development of tools focused on transport activities themselves and sprang from even earlier studies and tools to measure energy efficiency and consumption. Given the lesser contribution to GHG emissions from road construction and maintenance, it is only recently that studies have looked at these contributions, and tools have just started to be developed.

The choice of materials and techniques for road construction and maintenance has a wide variety of impacts, ranging from local pollution and environmental degradation to generation of GHGs and contributions to climate change. Manufacturers and engineering companies have studied the GHG contributions of their materials and alternate construction techniques. Findings include, for example, that concrete and cement are responsible for

**FIGURE 4 TOTAL $CO_2$ EMISSIONS OVER A 40-YEAR PERIOD FOR A 1 KM LONG AND 13 m WIDE ROAD DURING CONSTRUCTION, MAINTENANCE, AND OPERATION (LIGHTING, TRAFFIC LIGHTS, WINTER TREATMENT)**




*Source:* IVL Swedish Environmental Research Institute, 2001, Life Cycle Assessment of Road. A Pilot Study for Inventory Analysis, second revised edition.

50–160 percent more emissions than asphalt, and that recycling at the end of the life cycle may also provide substantial economic gains, for example, from sale of recycled materials.

## 3.2. Assessment of Existing Tools

To assess the existing situation, several available emissions calculation tools have been assessed. Figure 5 summarizes those that have been explored in this study.

To facilitate tool comparisons and identification of the relative pros and cons of each model, table 7 and figure 6 present a synthesis of all the tools related to road construction.

This review points out that currently:

- No tool has been used to calculate GHG emissions from road projects in the Asian region;
- Considering the global score, only five tools reach the average score of 5.5, mainly because of poor scores for the "dissemination" or "transparency" criteria of the specific road tools;
- Considering the road activities score, six tools have higher than the average score (more than 2): the Australian Victoria State tool (VicRoads), the Highways Agency carbon tool, the Technical University of Denmark tool (Road-Res), the IRF GHG calculator (CHANGER), the Egis infrastructure carbon tool, and the LCPC tool (Ecorce).

One could point out that the five leading tools on the basis of total score will not necessarily perform well when used in the context of road activities. The IRF GHG calculator, the Highways Agency carbon tool, and the Australian Victoria state tool are the only tools in both selections; they therefore are considered good reference tools.

The AFD tool and, to a lesser extent, the ADEME tool do not score well on specific road activities, and therefore could not be selected. The Australian Victoria State and the Highways Agency carbon tools are ready to use, focus on the main GHG emissions related to a road project,

**FIGURE 5 SOME OF THE EMISSIONS CALCULATIONS TOOLS REVIEWED**

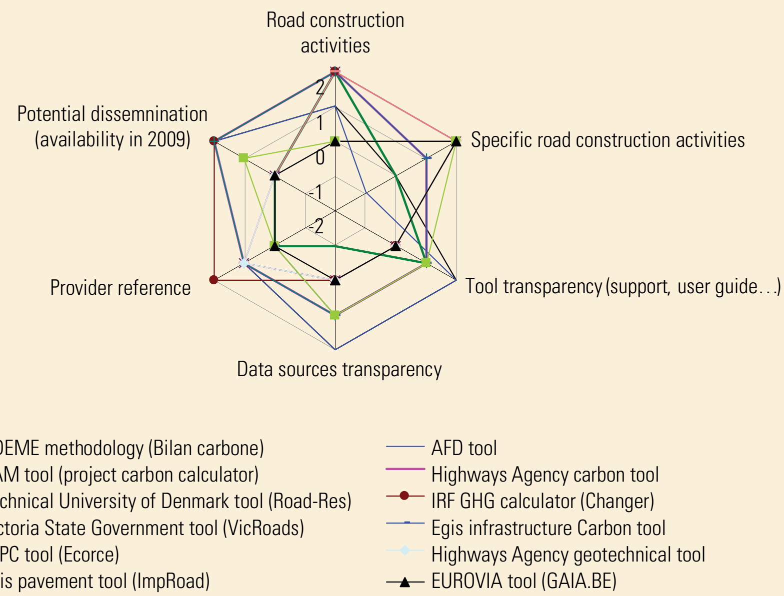

*Source:* Egis, 2010.

**TABLE 7 TOOLS COMPARISONS SYNTHESIS**

| | Road construction activities | Specific road construction activities | Tool transparency (support, user guide…) | Data sources transparency | Provider reference | Potential dissemination (availability in 2009) | Global score | "Road activities" score |
|---|---|---|---|---|---|---|---|---|
| ADEME methodology (Bilan carbone) | 1 | 0 | 2 | 2 | 1 | 2 | 8 | 1 |
| AFD tool | 1 | -1 | 2 | 2 | 1 | 2 | 7 | 0 |
| BAM tool (project carbon calculator) | 2 | 0 | 1 | -1 | 0 | 0 | 2 | 2 |
| Highways Agency carbon tool | 2 | 1 | 1 | 1 | 1 | 2 | 8 | 3 |
| Technical University of Denmark tool (Road-Res) | 2 | 2 | 0 | 0 | 1 | 0 | 5 | 4 |
| IRF GHG calculator (Changer) | 2 | 2 | 0 | 0 | 2 | 2 | 8 | 4 |
| Victoria State Government tool (VicRoads) | 2 | 1 | 1 | 1 | 1 | 2 | 8 | 3 |
| Egis infrastructure Carbon tool | 2 | 1 | 1 | 1 | 0 | 0 | 5 | 3 |
| LCPC tool (Ecorce) | 2 | 2 | 0 | 0 | 1 | 0 | 5 | 4 |
| Highways Agency geotechnical tool | 0 | 2 | 0 | 0 | 1 | 0 | 3 | 2 |
| Egis pavement tool (ImpRoad) | 0 | 2 | 1 | 1 | 0 | 1 | 5 | 2 |
| EUROVIA tool (GAIA.BE) | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 2 |

*Notes:* For each criterion, the notation ranges from -2 to +2 (unfavorable, rather unfavorable, neutral, rather favorable, and favorable.
These evaluations are very subjective and are the average opinions of the existing tool review team.

**FIGURE 6 TOOLS COMPARISON**




and provide total GHG emissions. They most likely could be applied to project specificities (for example, material transport by rail, specific data on pavement, and the like).

The IRF GHG calculator, the Technical University of Denmark tool, and the LCPC tool appear to be the most flexible, as they are modules-based. Currently, among these three, the IRF GHG calculator tool is the only one available for public use.

This assessment was done by using the selected existing tools in three case studies selected in the three pilot countries (China, Indonesia, and Vietnam).

### 3.2.1. Main Principles of Existing Tools

All existing tools share the same principles, considering:

- Materials that are elaborated from basic materials through a process that generates emissions, including, by extension, clearing activities;
- Transport (mostly of materials) at various stages of the construction process (supply to the plants, supply to the site, and transport on-site) that has emission factors;
- Construction processes with emission factors in the form of equipment emissions; and
- Others, to a lesser extent, such as personnel transport, management expenses, and so on.

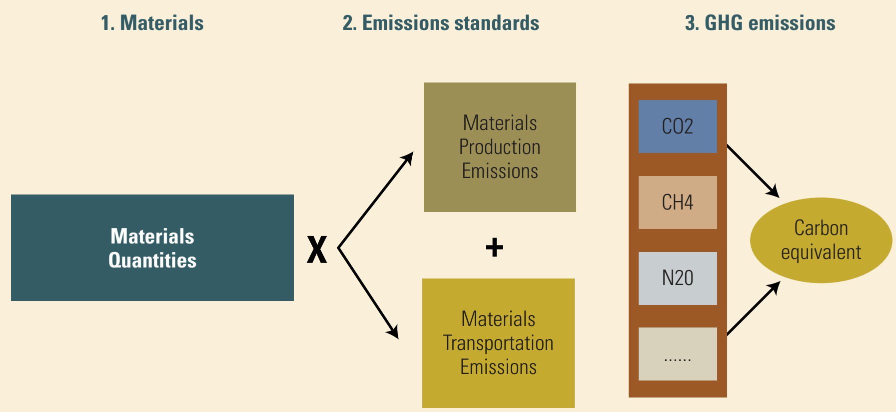
All tools are simple calculation tools that consider these generators and sum the emissions from the various stages of the construction process and from various components of the works.

### 3.2.2. Comparison of Calculations of Existing Tools

The results of the comparisons made among various existing tools underscore the following points:

- Total GHG emissions from a 1km road construction project (China and Indonesia case studies) range from 700 to 1,700 t-eq. $CO_2$. Total GHG emissions from a 1 km road maintenance/rehabilitation project (Vietnam case study) comprise between 300 to 500 t-eq. $CO_2$. This is consistent with the simplified calculation made on "typical roads."
- Depending on the calculator (and therefore on data sources for emissions factors), total GHG emissions for the same case study can vary over a large range of values; the relative difference is consistent (around 15 percent) in the Indonesia case study, and more mixed in the Vietnam (15–30 percent) and

**FIGURE 7 SIMPLIFIED CALCULATION PROCESS FOR MATERIALS**




*Source:* International Road Federation (IRF), 2008, Seminar on sustainable construction, Sustainable mobility, Solutions from road infrastructure.

China (0–30 percent) case studies. The relative differences in the value of the findings are rather limited, especially when one considers that emission factors within the various calculators vary.

- Materials-embodied energy and transport activities represent the most important part of total GHG emission—more than 80 percent—and on-site impacts represent less than 5 percent; and
- Regarding the calculators, the GHG emissions evaluation performed with the Egis calculator appears between the two others, and the evaluation performed with VicRoads (CHANGER) appears as the greater (smaller) evaluation, except for the Vietnam case study evaluation.

### 3.2.3. Characteristics and Limitations of Existing Tools

The following observations are noted:

- Although interfaces vary from summary (Excel-based) to more sophisticated, the architectures of the assessed calculation tools are essentially the same: emissions related to "on-site" activities (mainly construction equipment), transport of materials, and production of materials, are assessed through the multiplication of quantities by unit emission factors.
- The quantities used require detailed information regarding project construction, such as how many pieces of which types of equipment are present on site and their production rates. Detailed information is also required regarding the type of transport and sometimes materials composition (for example, the quantities of aggregates and binder in concrete, so that transport emissions can be calculated for aggregates from quarry to batching plant, and cement from cement plant to batching plant). This is very cumbersome for the user and such details are often not available at upstream stages, restricting the utility of the tool to informed specialists and to downstream stages.
- Sometimes the level of detail varies (diameter and age of trees cut are requested) while major approximations are made on other topics such as overall fuel consumption.
- The quality of reports also varies. However, and in general: the breakdowns of emissions are not given according to types of works, which makes using the results difficult—one cannot know on which aspects of construction to focus to reduce emissions. The use of results is made additionally difficult absent a way to export them in practical and editable soft format.
- The emissions factors vary from one tool to another. This does not create major problems, provided the user can modify these factors to suit the specific conditions of the project. In some cases though, (CHANGER) this is not possible; even extracting the emissions factors used for a calculation (using screen captures) is difficult (figure 8).

**FIGURE 8 CHANGER DATA INPUT SCREEN**

*Source:* IRF.

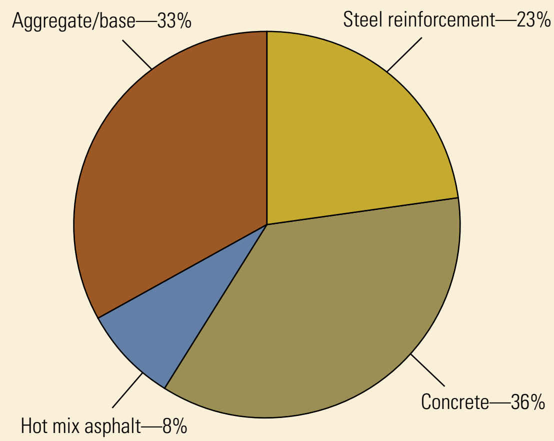
- The ease with which new materials, transport modes, vehicles, or construction equipment can be added also varies; in some cases, it is impossible. This may prevent users from comparing alternative construction methods that contractors would present during implementation (material alternatives, for example).
- The coverage of construction activities is not always clear and complete. Earthworks, road furniture, structures, and others are difficult to account for. Transport is simplified, and sometimes limited to road transport, while water and rail, which may play a significant role, are not available.

The figures following show typical graphic outputs from VicRoads and Egis (CHANGER does not provide similar outputs). The information provided cannot be directly used. For example:

- in the VicRoads tool, if there are concrete barriers whose contribution cannot be identified; and
- in the Egis tool, the contributions of various concrete components are not identified, and there might be pavement and structural concrete.

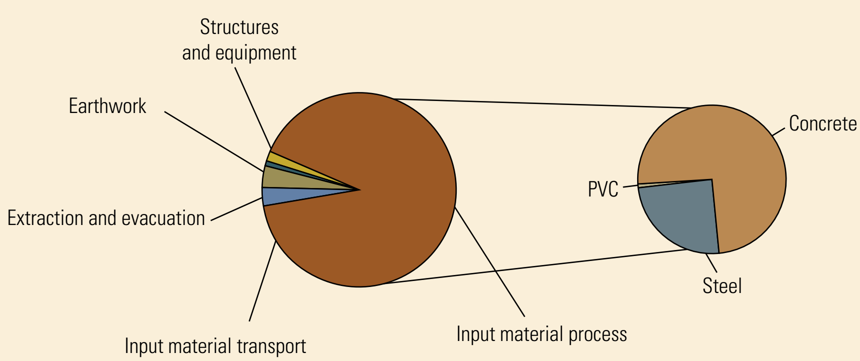
**FIGURE 9 EMISSIONS FROM A RING ROAD SECTION IN FRANCE—EGIS CALCULATOR**

Breakdown of Embodied GHG Emissions in Construction Materials for Indonesia Case Study




*Source:* Egis Infrastructure Carbon Calculator, 2010.

**FIGURE 10 BREAKDOWN OF EMISSIONS FROM A RING ROAD SECTION IN FRANCE—EGIS CALCULATOR**




*Source:* Egis Infrastructure Carbon Calculator, 2010.

## 3.3. Functions of the Tool

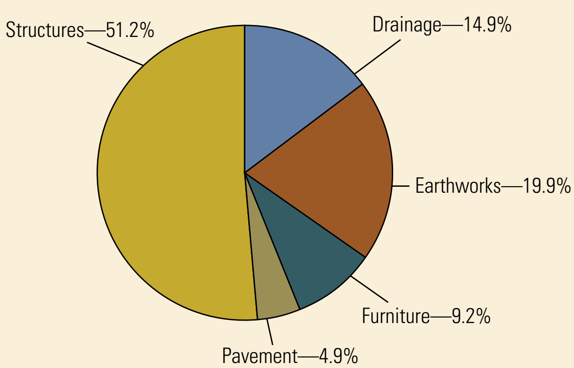
The above reasons led to a proposal to develop a calculation tool: The Greenhouse Gas Emission Mitigation Toolkit for Highway Construction and Rehabilitation—ROADEO. The tool is intended to perform the following tasks:

- Evaluate GHG emissions Evaluate GHG emissions from a road project. Such evaluation may take place at any of the following stages of a road project:
  - Planning/feasibility studies;
  - Detailed design;
  - Works/implementation; and
  - Completion of works/operation.
- Assess alternative construction practices to limit GHG emissions:
  - Identify technically relevant options based on the project's characteristics;
  - Evaluate GHG emissions of these options; and
  - Generate reports that provide useful information to the designer, planner, or construction manager (breakdown by type of work) to optimize the design and the implementation of the project.

The following principles were followed when the ROADEO calculator was developed:

- The tool should be open and transparent, allowing
  - addition of new equipment, new materials, new transport resources, and
  - easy access to and modification of GHG generators' characteristics, including emission factors; this makes sense where surveys are performed and their results used to update the calculator database.

**FIGURE 11 PROPOSED ROADEO CALCULATOR REPORT FORMAT**




*Source:* Egis ROADEO calculator, 2010.

- The tool should be easy to use, even at upstream stages, helping users (including non-engineers) assess quantities of GHG generators from project macro-quantities.
- The tool should be useful to planners and designers. It might be used at downstream stages for assessing or comparing bids or construction method statements.
- The reporting should be useful in the decision-making (engineering, planning) process to optimize the project, so should identify impacts of decisions.
- The tool should be used to identify, propose, and assess the impact of alternative construction or management practices

## 3.4. Assumptions, Modeling, and Calibration

For cases when the user at the upstream stage does not have the required details to perform the emissions calculation, a two-stage model has been designed.

- A first stage calculates quantities of items of road works, based on general characteristics of the project. The output of this stage is a theoretical "bill of quantities" at feasibility study stage, and the work items are broken down into "work series" reflecting the types of works.
- A second stage calculates the number of GHG emissions generators, based on the number of road works items and on general characteristics of the project. These generators are broken down into materials, transport, equipment, and others.

Table 8 summarizes ROADEO's 25 model parameters (16 for Stage 1, 9 for Stage 2) to be defined by the user.

This model is highly simplified. It is not based on engineering, but rather on empirical data, and does not intend to reflect real project values. Its intent is to provide rough estimates of a tentative nature for projects at the very initial stage. It has been used on several projects to check its accuracy, as shown in table 9.

While there are significant differences between the model and the project bill of quantities, the model has approached real quantities with an accuracy of less than 40 percent item by item, and with an overall accuracy that can be considered reasonable at upstream stages. Note that the impact of these differences on GHG emissions remains to be assessed.

### TABLE 8 PARAMETERS USED FOR ROADEO'S SUMMARIZED DESCRIPTION OF THE ROAD

| Parameter | Description | Unit | Stage |
|---|---|---|---|
| %ECD | Length of existing cross drainage as a percentage of requirement | % | 1 |
| %ELD | Length of existing longitudinal drainage as a percentage of length of road | % | 1 |
| %EWB | Parameter reflecting the balance between cut and fill | % | 1 |
| %GLP | General longitudinal profile | % | 1 |
| %MNT | Length of road in mountainous terrain as a percentage of road length | % | 1 |
| %RCK | Volume of rocky soil as a percentage of volume of soil | % | 1 |
| %URB | Length of the road project crossing urban areas as a percentage of road length | % | 1 |
| %WDB | Number of bridges to be widened as a percentage of number of bridges | % | 1 |
| CBR | California Bearing Ratio | % | 2 |
| EAL | Equivalent standard axle (8.2t) loading—ESAL | u | 2 |
| ECS | Existing cross section | m | 1 |
| L | Road project length | m | 1 |
| LW | Lane width | m | 1 |
| MW | Median width | m | 1 |
| NBL | Number of lanes | u | 1 |
| OST | Overlay structure type | list | 2 |
| PST | Pavement structure type | list | 2 |
| RTP | Road type | list | 1 |
| STH | Area where subgrade has to be treated with hydraulic binders | % | 2 |
| SW | Shoulder width | m | 1 |
| TBM | Type of barrier material | list | 2 |
| TSB | Type of structure (standard bridges) | list | 2 |
| TSM | Type of structure (major bridges) | list | 2 |
| TSW | Type of structure (wall) | list | 2 |
| TUN | Length of tunnel (not used pending further development) | m | 1 |
| WTP | Works type | list | 1 |

*Source:* Egis.

### TABLE 9 CASE STUDIES USED TO CALIBRATE THE ROADEO CALCULATOR MODEL

| Project | Country | Type | Comment |
|---|---|---|---|
| EINRIP | Indonesia | National roads rehabilitation | Including bridges |
| PRIP | Cambodia | Rural roads rehabilitation | |
| NPP | Vietnam | National road rehabilitation | Asphalt overlay no bridge |
| STDP | Sri Lanka | Expresswaynew alignment | |
| RPPF | Sri Lanka | Provincial roads widening | |
| TIIP | Sri Lanka | National road widening | Surface treatment |
| Rui-Gan Expressway | China | Expressway new alignment | |

*Source:* Egis.

## 3.5. Emissions Factors

Significant issues regarding emissions factors include:

- the different units used by different tools (tons, cubic meters, and so on)—an inconsistency that is not user friendly and could be a source of errors, as different densities, for example, are used to convert volumes into weights,
- the various compositions of composite materials, and
- the assumptions made on some materials, mostly in the case of cement, as shown in the table 10.

The emissions factors with high impact, and that vary significantly from tool to tool, include cement, steel, lime, and electricity. The three are somewhat related, as slag can be used in concrete, and electricity is the source of energy for the recycled steel used for steel bars.

To evaluate the impact of the uncertainty inherent in the steel emissions factor, a specific study was done on those emissions, based on the ratios in table 11. Indications are that the data provided by SETRA in the above table are closer to the actual figures. This should be the subject of further research.

Electricity is related to power production—coal, petrol, gas, hydraulic, nuclear. Depending on the country, the region, and even the plant and local power production strategies, electricity-related GHG emissions are subject to variations in the medium term.

Cement is widely used in road construction and rehabilitation, mostly for reinforced and prestressed concrete structures (bridges, culverts).

The cement alone accounts for 85 to 90 percent of the total GHG emissions of a cubic meter of ready-mix concrete for the most used cements (Classes CEM I & CEM II, according to European standard EN 206-1). A study performed by CEMEX, a major supplier of ready-mix concrete, for a building site in Paris shows a rate of 89 percent with a binary mixture of CEM I and fly ash. Aggregates, transport of all the raw materials to the batch-plant, mixing, and delivery to site (5 km) account for only 11 percent of the total. GHG emissions from concrete placement so are not provided.

**TABLE 10 EMISSIONS INTENSITIES WITHIN VICROADS, CHANGER, AND EGIS CALCULATORS**

| Material and product | Unit | Emission intensity (kg eq $CO_2$/unit) VicRoads | CHANGER | Egis calculator |
|---|---|---|---|---|
| Steel | t | 2,650 | 2,346 | 3,190 |
| Cement | t | 670 | 825 (25%) | 776 |
| Concrete (15% cement) | $m^3$ | 258 | | |
| Concrete (30% cement) | $m^3$ | 496 | | |
| Concrete (% cement, sand, aggregate) | t | | 163–269 | 249–351 |
| Hot mix asphalt (5% bitumen) | t | 10 | 29.40 | 54 |
| Aggregate | t | 8 | 10.32 | 11 |
| **Transport** | | | | |
| Medium truck (diesel) | veh.km | 0.83 | | 0.71 |
| Heavy truck (diesel) | veh.km | 1.58 | | 1.36 |
| PTAC 6.1–10.9 t | ton.km | | 0.60 | 0.53 |
| PTAC 11–21 t | ton.km | | 0.30 | 0.27 |
| **Energy** | | | | |
| Diesel | liter | 2.90 | 3.93 | 2.94 |
| Electricity | kw.k | 1.31 | 0.80 | 0.08 |

*Source:* Egis review of various calculators.
*Note:* PTAC—Poids Total Autorisé en Charge (total allowed weight when loaded).

**TABLE 11 EMISSIONS INTENSITIES FOR STEEL, ACCORDING TO VARIOUS SOURCES**

| Source | Year | kg $CO_2$/kg steel |
|---|---|---|
| ADEME | 2006 | 3,190 |
| US EPA | 1998 | 4,162 |
| US EPA | 2002 | 4,081 |
| US EPA | 2006 | 4,081 |
| OFEFP | 1998 | 3,241 |
| AEA Technologie | 2001 | 2,970 |
| MIES | 1999–2003 | 1,599 |
| SETRA | 2009 | 1,027–1,503 |

*Source:* Egis compilation of multiple agencies.

Table 12 compares GHG emissions for the production of 1 ton of cement for various types of cement. The classes are defined by the European Standard EN206-1:

- CEM I: cement (95–100 percent of clinker and up to 5- percent additions)
- CEM II: Composite cement (clinker + up to 35 percent additions)
  - CEM II/A (80–94 percent of clinker)
  - CEM II/B (65–79 percent of clinker)
- CEM III: Blast furnace slag
  - CEM III/A (35–64 percent of clinker)
  - CEM III/B (20–34 percent of clinker)
  - CEM III/C (5–19 percent of clinker)
- CEM IV: pozzolan cement
- CEM V: composite

**TABLE 12 GHG EMISSIONS IN KG EQCO$_2$ FOR THE PRODUCTION OF 1 TON OF CEMENT**

| CEM I | CEM II | CEM III/A | CEM III/B | CEM V |
|---|---|---|---|---|
| 866 | 629 to 759 | 461 | 247 | 502 |

*Source:* Info Ciment.

**TABLE 13 GHG EMISSIONS IN KG EQCO$_2$ FOR THE PRODUCTION OF 1 M$^3$ OF READY-MIX CONCRETE**

| CEM I | CEM II/A | CEM II/B | CEM V/A |
|---|---|---|---|
| 261 | 231 | 200 | 159 |

*Source:* Lafarge.

For 1 m$^3$ of ready-mix concrete, overall GHG emissions depending on cement type are shown in table 13.

Users must exert great care in selecting values or confirming default values that the ROADEO calculator proposes.

## 3.6. Tool Boundaries

ROADEO's boundaries are set for a practical reason: data readily available to users, under the best circumstances—upon completion of works, when all details should be known— usually comes from contractors' bills of quantities and internal information.

Such data generally identify the source of materials and equipment, up to their immediate origin or provider (quarries, manufacturers, importers, and so on) and indicate the means used to transport them to the site.

Getting information beyond these limits (initial location, production process and shipment of raw materials, spare parts for equipment, and the like) would require significant efforts that typical participants may not be willing to provide.

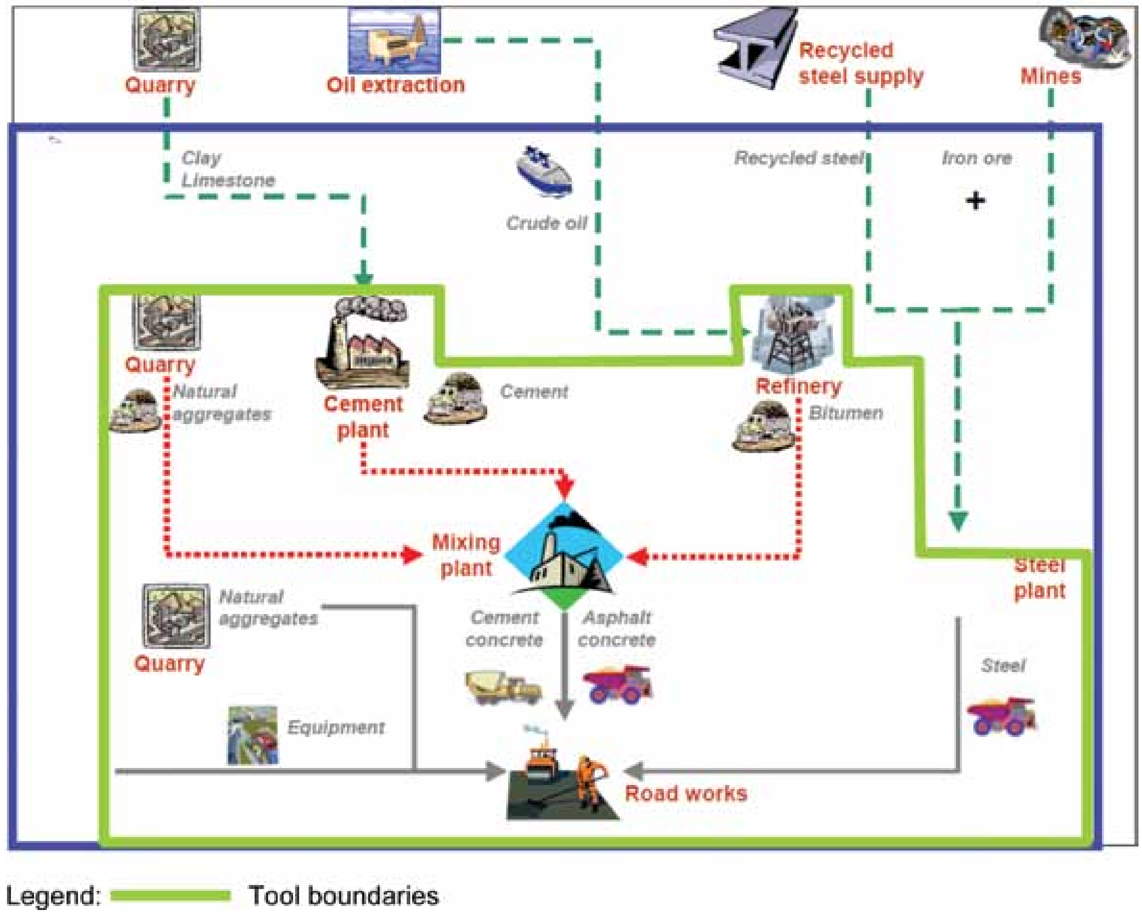
Figure 12 shows the boundaries set for ROADEO.

Within these boundaries, the ROADEO calculator considers the following:

- Materials and equipment tables
  Emission factors must take into account upstream GHG emissions resulting from the initial production of raw materials; fabrication and transport of equipment; and downstream GHG emissions (materials recycling, equipment maintenance, and end-of-life), beyond the boundaries.
- Transport table
  Within boundaries, a relevant set of origin and destination types is predefined, including at least the following:
  - Material plant (cement, refinery, steel, and so on);
  - Material source (quarry, forest, and so forth);
  - Mixing plant/workshop; and
  - Site

  Combinations of transport modes (main mode plus terminal mode, for example) are allowed for each origin-destination couple.

**FIGURE 12 ROADEO CALCULATOR BOUNDARIES**




*Source:* Laboratoire Central des Ponts et Chaussées.

4

# Alternative Practices to Reduce GHG Emissions

## 4.1. Overview

This chapter provides a synopsis of alternative practices, including:

- technical description of alternative practices,
- identification of inputs required for their implementation,
- assessment of corresponding GHG emissions, and
- estimates of variations in GHG emissions and construction costs compared with current/standard practices

The above information has been gathered into consistent categories of works components:

- Transport;
- Earthworks;
- Pavement;
- Structures; and
- Equipment/road furniture.

Alternative practices are compared with current practices.

## 4.1 Identification of Alternative Practices

For the purposes of this publication, indications of orders of magnitude of potential impacts of alternative practices on various components of road works are provided. While many alternative construction and rehabilitation practices have been identified that could potentially replace various current practices, only those believed to promise the greatest impact on GHG mitigation—and that are easily transferable to the pilot countries—are discussed.

For further information, appendix A summarizes all current road construction and rehabilitation practices against alternative international best practices explored. In addition, the reader is directed to annex 3 on the CD that accompanies this publication—"Identifying gaps between best practices from developed countries and practices in pilot developing countries and proposals for improving the situation"—for a more detailed investigation.

Alternatives discussed here include:

- modal shift and use of more efficient road vehicles for transport of materials,
- methods for excavation of hard soil,
- reduction in the use of lime as a means to stabilize soil,
- optimizing pavement structures for increased service life and reduced maintenance demands,
- implementation of combined semi-empirical and analytical pavement design standards, which can affect pavement thickness and material usage,
- asset overloading and operational management,
- impact on pavement roughness of reducing short-wavelength unevenness,
- selection of structure type as well as type and volume of steel used in structures, and
- significance of barrier types.

The following sections provide a description of the main findings on alternative practices.

### 4.2.1. Transport

Transport of materials represents about 30 percent of the GHG emissions of a road project. Of that amount, about 50 percent is related to local (less than 25 km) transport.

Reduction of emissions can be the result of:

- use of more efficient road vehicle fleets with a lower unit emissions ratio, which can be significant, as efficiency improves with the use of higher-payload trucks (an approximately 50 percent decrease in unit emissions and savings of more than 20 percent in total transport emissions), and
- modal shift from road to more efficient modes (rail or water have unit emissions 17 times lower) over long distances; further improvement can be up to 8 percent of total emissions after road transport has been optimized.

### 4.2.2. Earthworks

#### 4.2.2.1. Rock excavation

- Excavation in hard soil generates two to 3 times more GHG than in ordinary soil.
- The use of drilling rigs rather than light drillers is twice as productive, but produces 35 percent more GHG per cubic meter of rock excavated.
- Productivity of labor-intensive methods is 250 times lower, while involving 3 times more labor. If labor emissions are considered neutral, this is a significant reduction in GHG emissions.
- Explosives represent only 5–7 percent of the emissions of the excavation process.
- The use of explosives for excavation seems to produce fewer GHG emissions, as shown in table 14.
- Excavation and loading and transport to fill sites are of the same order of magnitude, at around 2kg $CO_2$eq./$m^3$ of excavated rock.
- Putting aside less than satisfactory health and safety considerations, the local lightly mechanized technique is the most efficient in terms of GHG emissions.

#### 4.2.2.2. Soil treatment

Except in cases where materials are not available locally (within less than around 150 km), soil treatment is not very effective in reducing GHG emissions, the result of emissions from and transport of lime.

It should be noted that studies are underway to assess interest in soil treatment in the context of sustainable development with respect to indicators other than GHG emissions.

### 4.2.3. Pavement

A number of alternative techniques have been identified and their potential impact assessed, based on the use of different materials (recycled, high modulus asphalt and others), design (combined bituminous-concrete structures, investment schedule and budget (which might affect pavement design) or construction technique (warm and half-warm asphalt mixture methods).

#### 4.2.3.1. Pavement structure types

- For initial construction, concrete pavements produce higher emissions. This may range from a factor of 1.6 (for thinner concrete sections) to 3 (for thick concrete sections) compared to the thin bituminous layers. However, depending on the maintenance and rehabilitation strategy, the life-cycle GHG emissions may be more comparable or may even favor concrete pavement.
- Optimized pavement structures (high-performance bituminous mixtures and Continuously Reinforced Concrete Pavement [CRCP] on bituminous base, which, according to recent studies, make optimal use of materials for concrete pavement structures) have lower emissions than nonoptimized structures.
- Orders of magnitude for the construction, maintenance, and end of life of pavement structures range from 65 to 175 kg/m².
- Cold mixtures as well as recycling technologies and materials have lower emissions (by a factor of three when compared to hot mixture bituminous structures).

**TABLE 14 RELATIVE IMPORTANCE OF EXPLOSIVES IN GHG EMISSIONS FROM EARTHWORKS TECHNIQUES**

| Excavation method | Output ($m^3$/day) | Fuel consumption (l) | Explosives (kg) | GHG (kg $CO_2$eq.) | GHG (kg $CO_2$eq./$m^3$) |
|---|---|---|---|---|---|
| Hammer | 1,000 | 864 | | 2,160 | 2.2 |
| Mining (light driller) | 1,250 | 480 | 500 | 1,469 | 1.2 |
| Mining (drilling rig) | 2,500 | 1,725 | 1,000 | 4,851 | 1.9 |

*Source:* Egis field data.

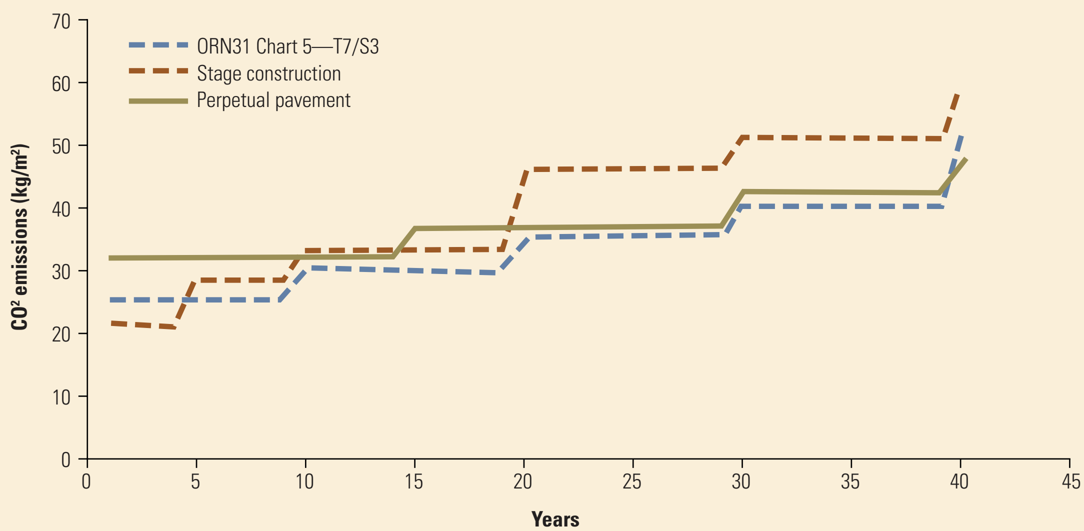
#### 4.2.3.2. Investment and maintenance strategies

- Maintenance represents 20–40 percent of overall emissions from pavement over 30 years, indicating that there are tradeoffs between construction and maintenance with regard to both cost and emissions.
- For the given life duration, taking into account the life cycle and standard maintenance scenarios for both structure types, concrete structures in general emit double the GHGs of composite structures, while bituminous structures emit the fewest GHGs.
- The relationship between maintenance and traffic depends on the investment strategy (initial construction and maintenance). Decision-makers and planners in developing countries are often hindered by budgetary constraints; thus the initial construction of a road and the maintenance strategy that is applied to the road may be afffected. Generally, greater initial investment is avoided, often at the cost of long-term cost or reduced maintenance practices. Maintenance strategies and a design catalogue biased toward increased initial investment and the above studies may not fully reflect the whole range of situations.
- Staged construction seems to lead to significantly higher total emissions. The perpetual pavement strategy seems to lead to slightly lower emissions than standard pavement structure after 40 years.
- It should be noted, however, that the damage factor after 40 years is significantly lower (that is, better structural condition of the asset) in the case of perpetual pavement.
- The impact of maintenance operations on traffic has not been taken into account, which may significantly affect the results for a T7 traffic class in TRL ORN31.
- The cost of user delays associated with traffic due to maintenance operations has not been taken into account in figure 13. In particular, this may affect the results for the T7 traffic class on a TRL ORN31 pavement. The traffic and pavement class refer to British standards.
- The above results do not take any discount rate into account.

#### 4.2.3.3. Overloading and impact of standards

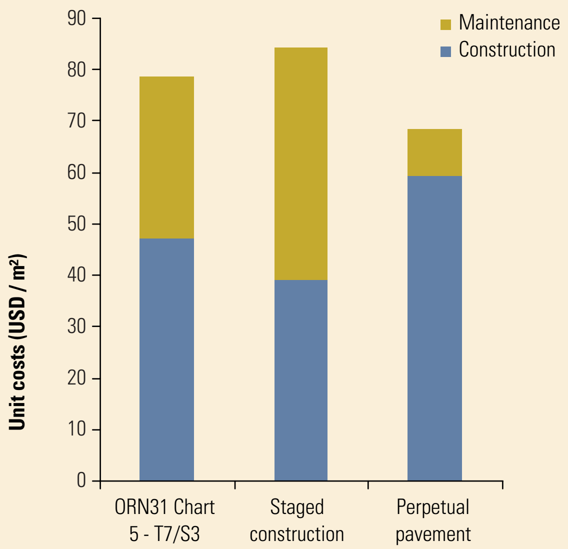
Significant discrepancies in GHG emissions can result from the use of different pavement design standards (from 0 to 17 percent, depending on traffic loads considered for this specific case study, and up to 45 percent in the latter comparison). For example, Vietnamese standards are based on empirical methods that attempt to model pavement structures as 2-layer or 3-layer equivalents. Alternative standards are based on combining semi-empirical (AASHTO 1193, TRL ORN 31) and analytical (AASHTO 2004, Austroads) methods that take into account the fatigue performances of road materials.

**FIGURE 13 CUMULATIVE GHG EMISSIONS FOR CONSTRUCTION AND MAINTENANCE ACTIVITIES, DEPENDING ON PAVEMENT CONSTRUCTION/MAINTENANCE STRATEGY**




*Source:* Egis.

**FIGURE 14 COMPARISON OF DISTRIBUTED COSTS BETWEEN INITIAL CONSTRUCTION AND MAINTENANCE ACTIVITIES, DEPENDING ON PAVEMENT CONSTRUCTION/MAINTENANCE STRATEGY**




*Source:* Egis.

The impact of overloading on the thickness of pavement structures and on corresponding GHG emissions is significant. It has been assessed at 23–49 percent of pavement emissions, depending on standards considered.

#### 4.2.3.4. Roughness

For a given speed, the maximum range in fuel consumption for different surface textures appears to be about 2 liters/100 km. Limiting rolling resistance caused by pavement texture could lead to significant reductions in GHG emissions in the long term—over the life-cycle of a given road section—although road safety requirements must be concurrently considered: if rolling resistance or road friction is reduced too greatly, vehicles will have braking and stopping problems, especially on wet surfaces.

The impact of pavement roughness on GHG emissions is far more significant than the impact of texture. Improvements in roughness, especially by reducing short-wavelength unevenness, could decrease fuel consumption by up to 4 liters/100 km, as assessed using a mathematical "suspension model."

Actions to ensure low roughness (such as proper construction techniques) are therefore important, although their impacts are difficult to estimate in advance.

### 4.2.4. Structures

- Bridge construction emits about 3 tons of $CO_2$ eq./m² of bridge deck.
- The structure's material has an impact; however, for a given structural type, this impact is typically less than 15 percent of the GHG emissions.
- The structure type has greater impact for a given material. Table 15 summarizes this impact; the more complicated the structure type, the higher the relative emissions.
- Steel is a major component of structures. Uncertainty about its emission factor, which relates to its origin and the technology used to produce it (whether recycled or not, origin of electricity, and so on) can have an impact of up to 30 percent for structure types making extensive use of steel and composite.
- Emissions from maintenance works could be considered as of the same magnitude as emissions during construction.

The relative emissions of typical roads on embankment, viaduct, and in tunnel are summarized in table 15.

**TABLE 15 COMPARISON OF GHG EMISSIONS FROM CONSTRUCTION OF EMBANKMENTS, BRIDGES, AND TUNNELS**

| GHG emissions from construction | Embankment ($tCO_2$eq./km) | Bridge ($tCO_2$eq./km) | Bridge/ embankment | Tunnel ($tCO_2$eq/km) @420$tCO_2$eq./(m²xkm) | Tunnel/ embankment |
|---|---|---|---|---|---|
| Expressway | 2,971 | 74,397 | 25 | 75,547 | 25 |
| National Highway | 739 | 35,649 | 48 | 37,773 | 51 |
| Provincial Road | 191 | 27,899 | 146 | 30,219 | 158 |
| Rural Road | 100 | 20,127 | 201 | 23,608 | 236 |

*Source:* Egis field data.

### 4.2.5. Equipment and Road Furniture

- Over a life cycle, the relative importance of emissions due to barriers ranges
  - from 4 to 23 percent of GHG emissions caused by pavement, in the case of steel or concrete barriers, and
  - from 2 to 12 percent in the case of wooden barriers.
- There may be significant interest in limiting the use of steel and concrete barriers, where possible, through adequate and safe design (safety zones cleared of obstacles, removal of aggressive spots, and the like), or replacing them with wooden barriers where traffic volumes and loads are sufficiently low. The potential impact could be up to 50 percent of the length of barriers, or from 2–12 percent of pavement emissions. This requires foresight in geometric design, and more effort during the design phase to minimize GHG emissions.

Lighting makes a significant contribution to GHG emissions when the operations phase is taken into account. It is outside of the scope of this publication to investigate this contribution in detail.

## 4.3. Integration into the ROADEO Calculator

Identified alternative practices have been included in the ROADEO calculator. The relevance of some to a particular situation can be summarily assessed through the values of parameters—high traffic, presence/absence of materials, relative importance of emissions attributable to a part of the works, and so on.

Datasheets describing the main issues, potential impacts, and reference materials (sources, for example) can be activated to give the user a first level of guidance to optimize the project. Additional guidance may be found in the technical annexes of this report.

Again, the ROADEO calculator cannot replace the sound engineering study that should always be undertaken in designing any alternative practice. However, it provides information to assess (i) where major opportunities for optimization lie, and (ii) the extent of such optimization. It also provides guidance on the engineering efforts to be deployed to achieve these optimizations.

## 4.4. Financial and Economic Analysis

In this study, two lines of analysis were followed—financial and economic.

### 4.4.1. Financial Analysis

The financial analysis presents the costs that would be incurred for road construction and maintenance, and any revenues from carbon credits that could be sold in carbon markets. The main assumptions were:

- A base-year price of US $15 per ton of carbon, increasing at 5 percent per year;
- A crediting period for emission reduction revenues that does not exceed 20 years; though this may exclude the benefits of reduction technologies over longer periods (50 or 100 years) it is the longest period permitted by the Clean Development Mechanism; if it could be extended, the economics would be more favorable;
- A discount rate of 6 percent; and
- An inflation rate of 3 percent.

Under these assumptions, the carbon market price (in constant price without inflation) reaches US$19 US/t after ten years and US$27 US/t after twenty years.

### 4.4.2. Economic Analysis

The economic analysis compares the costs and benefits to society of alternative methods of road construction and maintenance. For example, the analysis might include the cost of foreign exchange used to import materials or the value to the environment of improved contouring techniques. It would also compare the benefit(s) of reducing carbon emissions as against their potential market price. The main assumptions were:

- A base-year value for carbon emission reductions of US $85/ton, increasing at 3 percent per year;
- A period over which carbon emission reduction benefits accrue that is much longer than the financial case, and is based on the life of the project rather than the carbon market crediting period;
- Discount rate of 2 percent; and
- An inflation rate of 3 percent.

### 4.4.3. Analysis Conclusions

The analysis concluded:

- In many cases, the alternative (or best) practices resulted in lower costs on a life-cycle basis than traditional practices. They should be adopted regardless of GHG benefits.
- Based on the financial analysis, the revenues from carbon emissions reductions are minor compared to total costs; thus, no alternative practice would be justified purely on the basis of carbon revenues.
- Based on the economic analysis, using the social value of carbon (not its market value), the GHG benefits are significant, comprising, and in many cases even exceeding, up to 10 percent of total net benefits.

### 4.4.4. Policy Implications

Based on the current carbon market price, and on the discount rates for financial analysis, and also considering the conditionality to be met for benefiting from carbon credits likely to be generated through the CDM, carbon pricing can probably not be considered a realistic incentive for developing the GHG-friendly alternative practices that have been identified in the Task 6 findings for road construction, rehabilitation, and maintenance. Indeed, the carbon credit revenues likely to be generated by emissions reductions have very limited impact on the financial viability of the practices that have been analyzed. Accordingly, projects aimed at developing such practices would most probably not meet the additionality criterion of the CDM and would not be eligible to benefit from carbon credits. It has been verified that neither a dramatic increase in the carbon market price from US$15/ton to US$100/ton nor changes in other parameters (market price growth rate, discount rate, and the like) would substantially change these conclusions (the accompanying CD provides details). One reason why is the limitation of the evaluation period to 21 years, which is the maximum duration of the crediting period during which GHG-friendly project promoters can benefit from carbon credits generated by their emissions reductions.

On the contrary, the economic benefits of GHG emission reductions significantly enhance the economic return of projects aimed at developing the GHG-friendly alternative practices that have been identified.

This is particularly true for alternative practices affecting a road's life duration, maintenance operations, or both: the present value of economic benefits from GHG emission reductions, including those occurring over the long term, are significant, reaching around 10 percent or more of the total net benefits of applying such alternative practices. Nevertheless, most alternative practices studied in the present report are "intrinsically" economically viable; considering GHG emission reduction benefits would not transform an economically nonviable case into a viable one. A key reason for the economic benefits of GHG emission reductions is that the longer evaluation period adopted for the economic analysis, together with the low discount rate, allows taking into account those reductions' very long-term intergenerational benefits.

# 5

# Conclusions

## 5.1. Main Outcomes

The main contributions of the study under which this report has been prepared can be summarized as follows:

- Progress in understanding the main contributions to GHG emissions from road construction activities. This has been realized for various types of projects (covering a broad scope, from access-controlled divided highways to unpaved rural roads) and various work components (earthworks, pavement, drainage, structures, and road furniture).
- Development of an open, transparent, flexible emissions calculation tool that can be used at any stage of a project and provide information for decision making. ROADEO calculator inputs can be entered at the planning level (16 parameters to describe the road); the design level (based on a bill of quantities); or at implementation (as with other available tools, using quantities of materials and detailed descriptions of logistics and construction equipment used). This involves a model that is being calibrated based on data collection from several projects in Asia.
- Functionality previously unavailable—a major improvement for road planners and designers.
- Identification and documentation of alternative practices to reduce GHG emissions from construction and maintenance activities. While the identified alternative actions cover all work items, as well as institutional and planning issues, it is expected that others will be identified that can be integrated in updates of ROADEO, which will accept these actions and help the user select applicable alternatives that reduce GHG emissions.
- Carbon finance explored as a potential support for the implementation of alternatives. It has been found that the potential market-based financial benefits of alternative implementation are far less than the potential cost savings. The market price of carbon should be more than 10 times higher for such a mechanism to have an impact (except for optimization of materials transport). However, economic analysis based on the social cost of carbon, and on a longer assessment period, supports the greater impact of implementing alternative practices.

## 5.2. Challenges Ahead

While progress has been made, significant challenges remain:

- The lack of a unified source of information in East Asian countries (and in general) on GHG emissions;
- The uncertainty over (or lack of general agreement on) the values of emissions of some major contributors to road activities emissions (cement, steel, and so on) in the context of a life-cycle assessment. This is due in part to the lack of clarity on the role of by-products, and the role of end-of-life treatment (including recycling);
- The difficulties in assessing the changes in emissions contributions that GHG generators exhibit during the life cycle, and in adapting plans and design accordingly. GHG emissions vary highly depending

on the precise locations of materials sources (quarries, soil treatment, origin of cement, bitumen, and steel), on the choice of construction technology (for example, the type of asphalt mixing plant), or even on the construction schedule (for example, the need to work during the rainy season). The comparison of orders of magnitude between the variations due to the above factors, and the gains due to optimizations, make it difficult to define an optimized design at early stages;

- Insufficient awareness among stakeholders (road agencies, consultants, contractors, and concessionaires) that their actions at all stages of a project can contribute to reducing the $CO_2$ burden; and
- The need for a user community that helps improve the ROADEO calculator, based on experience gained while using it. To start with, it is hoped that this toolkit will be used to assess road projects' impacts and then optimize applicable aspects of the project.

**TABLE A1 SUMMARY OF CURRENT PRACTICES AND CORRESPONDING ALTERNATIVES**

| Area | General East Asian current practice | Identified alternative practice | Measures to be explored | Transferability to East Asian countries | Major/minor stake | Quantifiable gap | Gap assessment method | Comments |
|---|---|---|---|---|---|---|---|---|
| **General** | | | | | | | | |
| Procurement | Limited consideration of impacts on GHG emissions in procurement of works | Environmental criteria included in the procurement process | Include constraints on GHG emissions in technical specifications for contractors' bids to comply with | Difficult | Major | No | | Need for an evaluation tool—the ROADEO calculator might be used in this respect |
| Packaging | | Packaging adapted to the context: major contracts, design/build, local contracts, framework contracts, performance/outputs-based contracts | Build up the capacity of the road construction industry through efficient packaging allowing use of efficient technology | Easy | Major | No | | |
| Project Size | Difference between large-sized/smaller-sized projects:<br>– latest technology/high-efficiency equipment and plant used on major projects<br>– use of labor-intensive approach on smaller-sized projects (including rural roads) | Highly mechanized construction methods implemented with up-to-date technology | | Difficult | Minor | Yes | Compare GHG emissions resulting from labor-intensive practices/mechanized practices for 1km of typical highway | The share of emissions resulting from road construction equipment in overall GHG emissions for major highways is limited. However, mechanized works may induce the construction of temporary facilities (for example, access roads) which can significantly increase GHG emissions |
| Quality Assurance | Quality Assurance approach not systematically implemented | Quality Assurance widespread in the industry, including among employers, contractors, and consultants | Implement QA approach | Difficult | Minor | No | | |

**(continued)**

| Area | General East Asian current practice | Identified alternative practice | Measures to be explored | Transferability to East Asian countries | Major/ minor stake | Quantifiable gap | Gap assessment method | Comments |
|---|---|---|---|---|---|---|---|---|
| Geometry | Geometry sometimes overdesigned with respect to real traffic needs (over capacity) resulting in high GHG emissions | Lane width adjusted to safety and traffic requirements | Design standards to be fit for purpose and suited to local conditions | Easy | Major | No | | US standards (and western in general) are generous and space-consuming |
| Overloading management | Widespread overloading, limited enforcement | | Improve overloading enforcement | Difficult | Major | Yes | Evaluate additional costs and emissions due to overloading | |
| Carbon storage materials | | Use products that store carbon during their processing (wood, bamboo, plants, or other composite materials) | | Difficult | Minor | Yes | Collect/assess emission factors for carbon store materials (for example, wood, bamboo, jute) | |
| **Earthworks** | | | | | | | | |
| Embankment techniques | Use borrow pits for embankments and put bad excavated material in waste deposits | Use cuts treated with lime or cement for embankments | | Easy | Minor | Yes | – Compare GHG emissions from embankments made of treated soil vs. from borrow pits<br>– Compare GHG emissions between two alternative borrow pit/ waste deposit locations | Main parameters:<br>– Distance to borrow pit<br>– Quality" (CBR) of local material<br>– Type of transport<br>– Emission of cement/ lime<br>– Distance of lime/ cement plant<br><br>Main parameters:<br>– Distance to borrow pit<br>– Quality of local material (CBR)<br>– Type of transport |
| Labor intensity in excavation | Widespread excavation by hand using small handheld equipment | Use of mechanized excavators | | Easy | Minor | Yes | Compare GHG emissions from hand excavation/ mechanized excavation | Main parameters:<br>– Output of hydraulic hammer (big/small)/of blasting<br>– Fuel/power consumption of hydraulic hammer (big/ small)/of blasting |

(continued)

| Area | General East Asian current practice | Identified alternative practice | Measures to be explored | Transferability to East Asian countries | Major/ minor stake | Quantifiable gap | Gap assessment method | Comments |
|---|---|---|---|---|---|---|---|---|
| Labor intensity in rock crushing | Fragment rocky materials manually with a small machine | Blast rocky materials | | Easy | Minor | Yes | Compare GHG emissions from blasting/hand crushing | |
| Slope protection | Slope protection with steeper slopes | Standard slope without protection | Slope treatment criteria: high quantities of cut/fill | Easy | Minor | Yes | Compare GHG emissions of various techniques for slope stabilization | |
| Earthworks equipment | Use of excavator in general | Widespread use of loaders/scrapers | Encourage the use of scraper depending on quantities of cut/fill and percent of rock soil | Easy | Minor | Yes | Compare GHG efficiency of scraper/excavator/loader | |
| Truck size | Use of small trucks (6 wheels) | Widespread use of trailers | Optimize truck size depending on actual transport requirements | Easy | Minor | Yes | Compare GHG efficiency of small and large trucks | |
| **Drainage** | | | | | | | | |
| Drainage systems | Rain harvesting is not included in projects; it may be a saving in terms of GHG emissions | Efficient drainage design is an environmental requirement, especially on higher-grade network/expressways and in urban areas | Include appropriate drainage system in all road projects | Difficult | Major | No | | May involve additional GHG emissions |
| Lined drains | Lined drains cast in place | Precast or slipform cast lined drains | | Easy | Minor | No | | |
| Culverts | Culverts cast in place | Precast culverts | Encourage the use of precast drainage items (longitudinal drains, pipes) to limit the amount of concrete involved in drainage | Easy | Minor | Yes | Collect/assess emission factors for precast and cast in place concrete | |

(continued)

| Area | General East Asian current practice | Identified alternative practice | Measures to be explored | Transferability to East Asian countries | Major/ minor stake | Quantifiable gap | Gap assessment method | Comments |
|---|---|---|---|---|---|---|---|---|
| Ditches | | | | | | Yes | Compare GHG emissions from ditches built manually or cast with a machine as for New Jersey barriers | |
| **Pavement** | | | | | | | | |
| Pavement materials | Hot mix asphalt concrete | High modulus asphalt materials | Replace hot mix asphalt with half-warm asphalt mixtures depending on traffic volumes, type of roads, and climate | Easy | Major | Yes | Compare hot mix asphalt with half-warm asphalt mixes and standard asphalt concrete | |
| Pavement materials | Hot mix asphalt concrete | Warm and half-warm asphalt mixtures | Replace hot mix asphalt with warm and half-warm asphalt mixes depending on traffic volumes, type of roads, and climate | Easy | Major | Yes | Compare warm and half-warm asphalt mixtures and standard asphalt concrete | |
| Pavement management strategy | Short duration design life | Perpetual pavement (i.e., thicker pavement at construction stage with less maintenance afterwards) | Use perpetual pavement design and limit maintenance | Easy | Major | Yes | Compare perpetual pavement approach and standard design | Applicability depends on traffic volumes and type of roads. |
| Pavement materials | Very first beginning of recycling | Recycling is developing | Promote relevant techniques depending on type of works (rehabilitation, existing road, widening), project size, and presence of an asphalt plant | Easy | Major | Yes | Existing studies already available in the literature | There is potential for recycling in China because of large amounts of homogenous materials remaining from the existing network that is currently being upgraded. However, the technology used to recycle is not widely available and it remains unclear who owns the recycled material; issues remain regarding cost assignment and payment policy |

(continued)

| Area | General East Asian current practice | Identified alternative practice | Measures to be explored | Transferability to East Asian countries | Major/ minor stake | Quantifiable gap | Gap assessment method | Comments |
|---|---|---|---|---|---|---|---|---|
| Pavement materials | Concrete pavement | Use of long life duration (30 years) concrete pavements (JPCP or CRCP) for major highways and motorways | Concrete pavement design and construction to be documented | Easy | Major | Yes | Compare GHG emissions from flexible pavement/ concrete pavement | Development of the use of cement with pozzolan fillers (addition of lime-filler and fly-ash) rather than of ordinary cement |
| Pavement materials | Use of local materials | Standards applicable to selection of materials, including local materials | Establish/update standards for selection of local and recycled materials | Easy | Minor | No | | |
| Pavement materials | Wide preference for paved rural roads | Optimized techniques for gravel roads construction, maintenance, and management | Prefer gravel roads or surface treatment to asphalt concrete whenever possible (low traffic, minor roads) | Easy | Major | Yes | Compare with a rural road with intermediate level of traffic, and perform life-cycle analysis on it | |
| Roughness | Roughness | Roughness criteria set as a performance target | Implement roughness control with high performance equipment | Difficult | Major | Yes | Existing studies already available in the literature | Major impact of roughness on GHG emissions during operation |
| Pavement materials | Soil stabilization | Subgrade stabilization | Various techniques are available | Easy | Major | Yes | Existing studies already available in the literature | Stabilization seems to be very emission-prone and may not be recommended for GHG emissions mitigation |
| Pavement materials | | Use of agricultural products (binders) in pavement | | Easy | Minor | Yes | Compare GHG emissions resulting from the use of agricultural/ industrial products in pavement | |
| Pavement materials | | Use of absorbing materials | Spread this technique | Easy | Medium | Yes | Assess GHG emissions captured by the improved pavement materials | Effectiveness of the technique to be further assessed. |

(continued)

| Area | General East Asian current practice | Identified alternative practice | Measures to be explored | Transferability to East Asian countries | Major/minor stake | Quantifiable gap | Gap assessment method | Comments |
|---|---|---|---|---|---|---|---|---|
| **Structures** | | | | | | | | |
| Bridge design | | | | Easy | Major | Yes | Compare GHG emissions for different types of bridges | |
| Bridge design | Limited use of steel/mixed structures for lack of steel on the market resulting in high price | Use of composite (concrete/steel) bridges as efficient structures | Use composite bridges (steel/concrete) | Easy | Minor | Yes | Compare emissions of composite structures with standard structures | |
| Interchanges | | Compact design of interchanges | Optimize geometric design to minimize quantities of structural concrete | Easy | Minor | Yes | Compare GHG emissions from overdesigned and standard interchanges | |
| Structural design | Low characteristics of concrete | Long-life design | – Implement long-life structural design depending on traffic and type of road<br>– Adjust standards and specifications; improvement of design criteria in order to improve life-cycle duration | Difficult | Minor | Yes | Compare GHG efficiency depending on concrete quality | |
| Alignment selection | | Optimized alignment to avoid tunnel/bridges sections | Optimize geometric design to minimize quantities of structural concrete | Easy | Major | Yes | – Compare GHG emissions for 1 km of tunnel or bridge with 1 km of cut/fill<br>– Compare tortuous vertical alignments involving cuts and fills with a smoother one involving viaducts and tunnels | Main parameters:<br>– Width of road (2 lanes/2X2 lanes)<br>– Height of embankment<br>– Type of bridge<br><br>Main parameters:<br>– Traffic volume forecast (impact on operations)<br>– Design speed<br>– Design life<br><br>Operation period to be also considered |

(continued)

| Area | General East Asian current practice | Identified alternative practice | Measures to be explored | Transferability to East Asian countries | Major/ minor stake | Quantifiable gap | Gap assessment method | Comments |
|---|---|---|---|---|---|---|---|---|
| Tunnels and cuts | | | | Difficult | Major | Yes | Compare GHG emissions from a tunnel and a cut of the same depth | Main parameters:<br>– Cross-section width<br>– Cut depth<br>– Type of tunnel |
| Bridges and embankments | | | | Difficult | Major | Yes | Compare GHG emissions from a bridge and an embankment of the same height | Main parameters:<br>– Cross-section width<br>– Height of embankment<br>– Type of bridge |
| Structural materials | | High-performance concrete | Promote the use of high-performance concrete through specific requirements included in technical specifications | Easy | Minor | Yes | Compare GHG emissions from 1m$^3$ of high performance concrete with 1m$^3$ of standard concrete | |
| Structural materials | | | Use of cement derived from dry production, concrete made with cement substitutes such as pulverized fuel ash, and so on | Difficult | Minor | No | Document cement unit emission factor | Modernization of cement plants |
| Structural materials | | Recycling (concrete, steel) | Develop guidelines for recycling of structural materials and promote their usage | Easy | Major | Yes | Compare emission factors for recycled and natural aggregates | |
| Structural materials | Retaining wall made of reinforced concrete | Reinforced earth wall with gabions outerface | | Easy | Minor | Yes | Compare GHG efficiency of reinforced concrete and reinforced earth | |

**(continued)**

| Area | General East Asian current practice | Identified alternative practice | Measures to be explored | Transferability to East Asian countries | Major/minor stake | Quantifiable gap | Gap assessment method | Comments |
|---|---|---|---|---|---|---|---|---|
| **Road Furniture** | | | | | | | | |
| Concrete barriers | Cast in place/precast | Use of slipform for concrete barriers | Promote the use of slipforms for concrete barriers | Easy | Minor | No | | Might not be better in terms of GHG emissions |
| Barriers materials | | | | Difficult | Major | Yes | Compare GHG emissions from steel and concrete guardrails with those made of wood or bamboo | Safety considerations need to be taken into account |
| **Maintenance** | | | | | | | | |
| Asset management strategy | General absence of asset-management strategy | Optimized design and construction to provide the best possible level of service within the available budget | – Improve maintenance planning<br>– Take into account maintenance in design and construction | Easy | Major | Yes | Compare GHG emissions of an optimized strategy and a nonoptimized strategy | Institutional issue: prioritization of works, data collection, and management |
| **Work Zone Traffic Management** | | | | | | | | |
| Traffic management | | – Organize and study work zone traffic management<br>– Mitigate congestion as well as ensure safety and comfort<br>– Plan works to decrease impact on users | Suggest work zone traffic management planning, possibly with tools such as Quickzone (FHWA) and indicate how to use these tools to evaluate GHG emissions | Easy | Major | Yes | Assess GHG emission savings from efficient traffic management and congestion avoidance | Need for another tool; outside of scope of the ROADEO calculator |

# ROADEO User Manual

## Model Framework and Assumptions

## Introduction

### Purpose of this Document

This appendix has been developed as part of an effort to prepare a toolkit for the evaluation and reduction of GHG emissions in the road construction industry. This is an abridged version of the User Manual. For a complete version that includes a more detailed overview of assumptions made an in-depth explanation of the development of equations used to estimate the various parameters for quantities of road works items within the algorithm, and alternative practice data sheets, the user is referred to the complete User Manual on the CD that accompanies this document.

The User Manual is intended to provide guidance to the user of the GHG emissions evaluation and reduction tool "Greenhouse Gas Emission Mitigation Toolkit for Highway Construction and Rehabilitation" (ROADEO, ROADEO calculator, the Toolkit), which takes the form of software.

The purpose of this document is to

- describe the structure of the software and explain the logic behind its development, so that users may successfully implement it, and
- detail the assumptions made to assist ROADEO calculator users who may not have the comprehensive information required to assess GHG generators.

The modelling of GHG emissions is not covered by this document. The user may refer to annex 1"Introduction to GHG Emissions in Road Construction and Rehabilitation" for information and guidance on this aspect. This information is found on the CD that accompanies this document.

These assumptions, as will be evident from further reading, are not expected to provide accurate results. However, in the absence of information, and especially at early stages of projects (planning and early feasibility study stages, for example) the model can provide orders of magnitude.

The model is highly empirical; it has very little interface with engineering considerations, apart from some considerations of pavement. Therefore, it should be used with great care.

It is expected that feedback from experience will allow major improvements.

### Structure of the Document

This document first presents the structure of the ROADEO calculator, then describes the overall model principles, and finally, details estimation of GHG generators, in terms of materials, equipment, and transport. Practical guidance is also given in a specific section on best practices.

A report on the calibration of the model used in the ROADEO calculator appears in an appendix.

### Notice

The following facts should be noted by the reader and ROADEO calculator users:

- The tool is the result of a somewhat contradictory effort to
  - make it as open as possible, so users can adjust most of the parameters affecting GHG emissions calculations and integrate their specific project conditions into the considerations and calculations, and
  - make it easy to use and accessible to a wide range of users who are not GHG or road construction specialists;
- The decisions made by users in selecting values for the calculation parameters may have a major impact on the results. The ROADEO calculator provides guidance and orders of magnitude to assist in this difficult task. However, the current status of calculation parameters selection and available information still leave space for major uncertainties. As discussed in the review of GHG provided with the Toolkit, sources sometimes disagree significantly on values to be considered.
- Some parameters cannot be precisely assessed at upstream stages; any calculation should be accompanied by a short note summarizing the assumptions made and the limits or risks of the calculation.
- Engineering or empirical results available from the ROADEO calculator may not represent the specific condition of the user's project, and careful consideration should be given before using the default values. These are provided to help users identify main issues and their orders of magnitude.

## Calculation Tool Architecture

### General Requirements

#### Objective

ROADEO, along with its User Manual and a manual on GHG emissions and best practices, comprises a toolkit for the evaluation and reduction of road construction GHG emissions.

The ROADEO calculator is intended to perform the following tasks:

- Evaluate GHG emissions Evaluate GHG emissions from a road project. Such evaluation may take place at any of the following stages of a road project:
  - Planning/feasibility studies;
  - Detailed design;
  - Works/implementation; and
  - Completion of works/operation.
- Assess alternative construction practices to limit GHG emissions:
  - Identify technically relevant options based on the project's characteristics;
  - Evaluate GHG emissions of these options; and
  - Generate reports that provide useful information to the designer and planner (breakdown by type of work) to optimize the GHG-relevant design and implementation of the project.

The ROADEO calculator does not perform road engineering designs, nor does it compute quantities. However, it enables identification of relevant alternatives to be further explored by users, with the support of the manual of best practices and through additional engineering studies as required.

Though the ROADEO calculator can be used at all stages of a project, it is most useful at upstream stages (planning and design) where other tools—those available and those under development—do not offer comparable functionality.

### Programming Environment

The ROADEO calculator was developed as a standalone spreadsheet. It does not include any macro and it is compatible with most versions of Microsoft Excel and Open Office, regardless of the OS platform. All parameters, default values and formulas can be accessed without password protection through a familiar, flexible, and transparent user interface.

### User Interface Language

Users may switch from one interface language to another in real time through a dedicated menu.

### Tool Organization

Figure B1 shows the general organization of the tool, including main user steps, data inputs/outputs and calculation protocols.

## Data Arrangements

### Data Transparency and Flexibility

The ROADEO calculator is based on transparent assumptions. Each variable is accessible to users and its value can be customized.

Data used for calculations comes from either

- built-in values initially proposed within the tool for selected tables and variables,
- suggested values proposed by the tool based on built-in values and calculations, or
- user-defined values imported by users or directly set by users (through user forms or table editing) to replace built-in or suggested values, either temporarily (project specific data) or permanently (calibration data).

### Database Structure

The database structure cannot be modified by users, but its contents may be adjusted—users can add or remove rows in each table, and change the value of any cell.

The database structure consists of one predefined table for each GHG generator:

- Materials used;
- Equipment used; and
- Transport variables.

Each GHG Generator has multiple associated variables falling into four groups:

1. Works Components: These are predefined tables. Each works component has multiple associated variables, allowing users to specify their project's characteristics and quantities. Users can duplicate works components tables and create new ones (by duplicating a specific component with generic contents (hereinafter "others") depending on actual project requirements— for example, multiple types of bituminous pavement, tunnels, ITS, and so on.
2. Characteristics: Variables providing basic information on each GHG generator (designation, material's physical composition, type, transport mode, origin-stops-destination, and the like).
3. Quantifying Data: Measurement variables used for emissions calculations for each GHG generator (volume, weight, capacity, distance, fuel/electricity consumption, and so on), each one to be filled in with a predefined measurement unit.
4. GHG Emission Factors: kg $CO_2$ equivalent/selected measurement unit.

Table B1 shows a simplified view of GHG generators distributed by works components.

Each column and each row has multiple associated variables. GHG emissions are calculated by combining (factoring and aggregating) these variables together.

FIGURE B1 ROADEO CALCULATOR TOOL ORGANIZATION

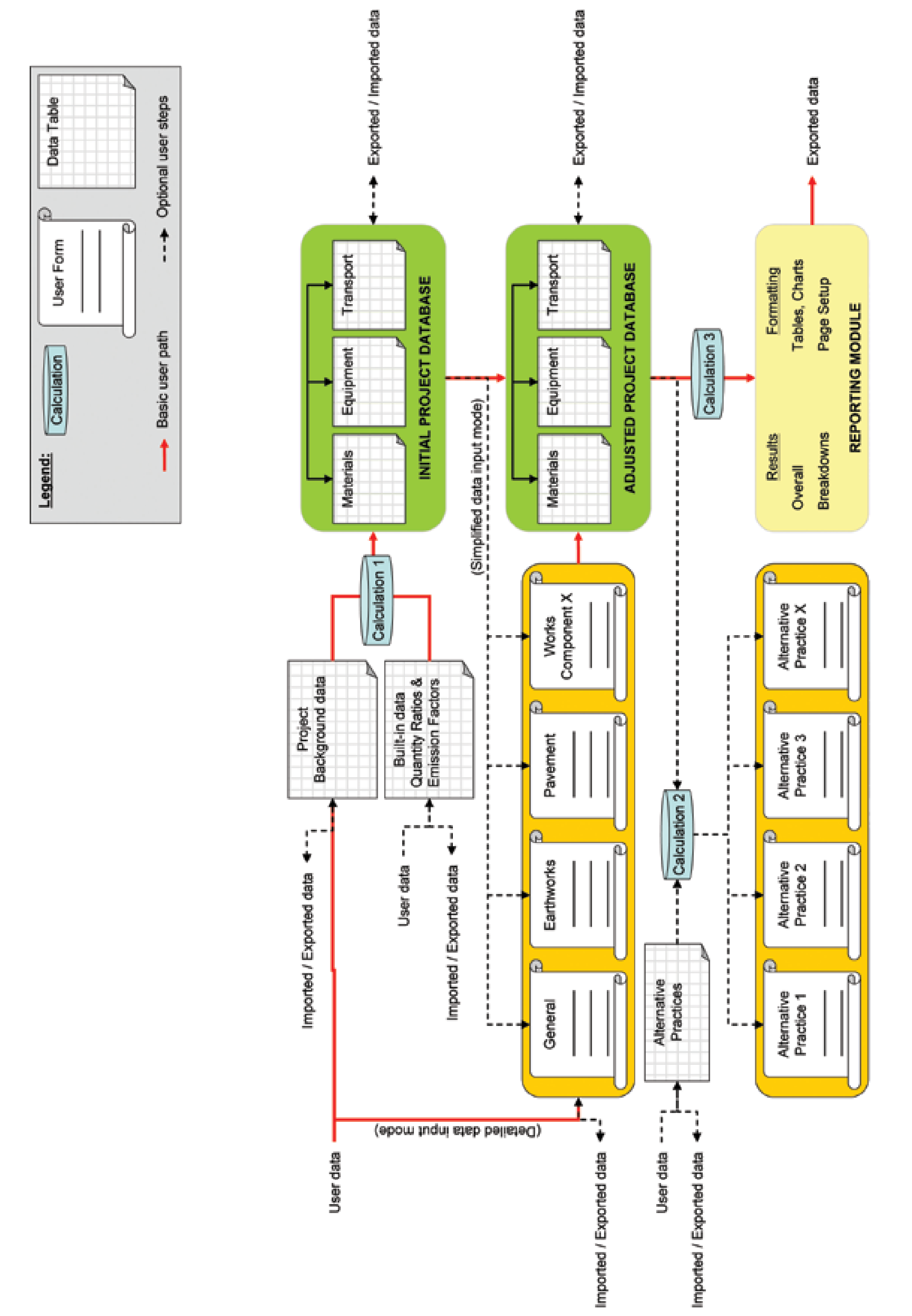


**TABLE B1 COMBINATION OF GHG GENERATORS AND WORKS COMPONENTS**

| GHG Generators works components | Materials | Equipment | Transport |
|---|---|---|---|
| Earthworks | | | |
| Drainage | | | |
| Utilities | | | |
| Pavement | | | |
| Structures | | | |
| Furniture | | | |
| Landscaping | | | |
| Management | | | |
| Others | | | |

## General Model Framework

### Architecture

The model included in ROADEO to assist users at upstream stages of projects (when all detailed information is not available) works in two stages.

In Stage 1, the user is able to calculate quantities of road works items based on general characteristics of the project. The output of this stage is a "bill of quantities" at the feasibility study stage, and the works items are broken down into "works series" reflecting the types of works.

In Stage 2, the user can calculate the number of GHG emissions generators, based on the quantities of items of road works and on general characteristics of the project. These generators have been broken down into materials, transport, equipment, and others.

### Parameters/Background Data

The purpose of the model is to provide outputs as close as possible to reality, while keeping the need for user inputs minimal, as a high level of need for inputs may lead to:

- lack of interest among nontechnical users, and
- high costs or an overly long period for data collection.

The background data that the user is required to enter in ROADEO are as follows.

Table B2 shows the parameters used in calculations during Stage 1. The assumptions made and equations used to estimate quantities for each item of works are elaborated in chapter 4 of the full-length User Manual. The user is invited to refer to it for a detailed overview of the Stage 1 inputs. Parameters used in calculations of Stage 1 are presented in table B3. Table B4 summarizes the 25 model parameters (16 for Stage 1, 9 for Stage 2) to be defined by the user.

**TABLE B2 LIST OF PARAMETERS USED IN CALCULATIONS OF STAGE 1 OF THE MODEL**

| Parameter | Description | Unit | Comment and explanation |
|---|---|---|---|
| %ECD | Length of existing cross drainage as a percentage of requirement | % | User input:<br>• 0%: no existing cross drain<br>• 100%: all required drains exist |
| %ELD | Length of existing longitudinal drainage as a percentage of length of road | % | User input:<br>• 0%: no existing longitudinal drain (also value for new project)<br>• 100%: all required drains exist |
| %EWB | Parameter reflecting the balance between cut and fill | % | User input:<br>• 100%: cut is wholly reused in fill<br>• 0%:cut is wholly evacuated |
| %GLP | General longitudinal profile | % | User input:<br>• –100%: cut only<br>• +100%: fill only |
| %MNT | Length of road in mountainous terrain as a percentage of road length | % | User input |
| %RCK | Volume of rocky soil as a percentage of volume of soil | % | User input |
| %URB | Length of the road project crossing urban areas as a percentage of road length (in%) | % | User input |
| %VET | Volume of embankment to be treated as a percentage of the volume of cut reused | % | User input |
| %WDB | Number of bridges to be widened as a percentage of number of bridges | % | User input |
| A1 | Parameter | | |
| A2 | Parameter | | |
| A3 | Parameter | | |
| A4 | Parameter | | |
| A5 | Parameter | | |
| A6 | Parameter | | |
| A7 | Parameter | | |
| A8 | Parameter | | |
| A9 | Parameter | | |
| A10 | Parameter | | |
| CGA | Area of clearing and grubbing | $m^2$ | |
| CUE | Volume of cut evacuated | $m^3$ | |
| CUR | Volume of cut reused as fill | $m^3$ | |
| CUT | Volume of cut | $m^3$ | |
| DSA | Directional sign area | $m^2$ | |
| ECS | Existing cross section | m | User input:<br>• Width of existing road including shoulders<br>• 0 for new projects |
| FBP | Volume of fill from borrow pit | $m^3$ | |
| FIL | Volume of fill | $m^3$ | |

**(continued)**

**TABLE B2 CONTINUED**

| Parameter | Description | Unit | Comment and explanation |
|---|---|---|---|
| HCF | Average height of cut and fill | m | |
| HRE | Volume of hard rock evacuated | $m^3$ | |
| HRRP | Volume of hard rock reused for pavement | $m^3$ | |
| HRRF | Volume of hard rock reused for fill | $m^3$ | |
| IBA | Interchanges bridge deck area | $m^2$ | |
| ILCT | Dry metric tons/ha for selected initial land cover types | ton/ha | *Source:* 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Values for Continental Asia) |
| L | Road project length | m | User input |
| LBC | Length of box culverts | m | |
| LBR | Length of barriers | m | |
| LED | Length of earth longitudinal drain | m | |
| LLD | Length of lined longitudinal drain | m | |
| LPC | Length of pipe culverts | m | |
| LW | Lane width | m | User input |
| MBA | Deck area of major bridges on main section | $m^2$ | |
| MW | Median width | m | User input |
| NBL | Number of lanes | u | User input |
| NCS | New cross section | m | |
| NPA | New pavement area | $m^2$ | |
| NPS | Number of vertical signs (police) | u | |
| NSL | Number of streetlights | u | |
| OPR | Area of other paved roads | $m^2$ | |
| POA | Pavement overlay area | $m^2$ | |
| RTP | Road type | list | User input:<br>• Expressway • Provincial road<br>• National road • Rural road |
| SBA | Deck area of standard bridges on main section | $m^2$ | |
| SGP | Area of subgrade preparation | $m^2$ | |
| SW | Shoulder width | m | User input |
| TEA | Tunnel excavation volume | $m^3$ | |
| TLV | Tunnel lining volume | $m^2/m$ | Area of wall lined per length of tunnel |
| TUN | Length of tunnel | m | User input |
| VET | Volume of embankment treatment | $m^3$ | |
| WAL | Area of walls | $m^2$ | |
| WBA | Wayside amenities area | $m^2$ | |
| WPA | Wayside amenities pavement area | $m^2$ | |
| WTP | Works type | list | User input:<br>• New alignment • Rehabilitation<br>• Widening |

### TABLE B3 LIST OF PARAMETERS USED IN CALCULATIONS OF STAGE 2 OF THE MODEL

| Parameter | Description | Unit | Comment and explanation |
|---|---|---|---|
| ASO | Area of surface dressing for overlay | $m^2$ | |
| CBR | California Bearing Ratio | % | User input<br>• to be homogeneous for the whole road |
| DAS | Distance asphalt plant—site | km | |
| DBS | Distance batching plant—site | km | |
| DCB | Distance cement plant—batching plant | km | |
| DCF | Distance cut on site—fill on site | km | |
| DCS | Distance cement plant—site | km | |
| DQA | Distance quarry—asphalt plant | km | |
| DQB | Distance quarry—batching plant | km | |
| DRA | Distance refinery—asphalt plant | km | |
| DRS | Distance refinery—site | km | |
| DSB | Distance site—borrow pit | km | |
| DSD | Distance site—disposal site | km | |
| DSS | Distance steel plant—site | km | |
| EAL | Equivalent standard axle (8.2t) loading—ESAL | | User input:<br>• Basic traffic<br>• Truck rate<br>• Traffic growth<br>• Design life |
| MHB | Mass of hydraulic binder | t | |
| OST | Overlay structure type | list | User input:<br>• Bituminous<br>• Gravel<br>• Surface dressing |
| PST | Pavement structure type | list | User input:<br>• Concrete pavement<br>• Bituminous pavement on granular materials<br>• Bituminous pavement on hydraulic bound materials<br>• Bituminous pavement on bituminous bound materials<br>• Surface dressing<br>• gravel |
| STH | Area where subgrade has to be treated with hydraulic binders (as a % of subgrade preparation area) | % | User input |
| TBM | Type of barrier material | list | User input:<br>• Concrete<br>• Steel<br>• Timber |
| Ti | Thickness of pavement layer No i | mm | Thickness of pavement layers calculated by the model on the basis of EAL, CBR, and PST |
| TSB | Type of structure (standard bridges) | list | User input:<br>• Composite (steel/concrete)<br>• Concrete (reinforced/prestressed) |
| TSM | Type of structure (major bridges) | list | User input:<br>• Composite (steel/concrete)<br>• Concrete (reinforced/prestressed)<br>• Steel |

**(continued)**

**TABLE B3 CONTINUED**

| Parameter | Description | Unit | Comment and explanation |
|---|---|---|---|
| TSW | Type of structure (wall) | list | User input:<br>• Steel (sheet pile)<br>• Reinforced concrete<br>• Reinforced earth |
| VBO | Volume of bituminous concrete for overlay | $m^3$ | |
| VGO | Volume of gravel for re-gravelling | $m^3$ | |

**TABLE B4 LIST OF PARAMETERS TO BE DEFINED BY THE USER**

| Parameter | Description | Unit |
|---|---|---|
| %ECD | Length of existing cross drainage as a percentage of requirement | % |
| %ELD | Length of existing longitudinal drainage as a percentage of length of road | % |
| %EWB | Parameter reflecting the balance between cut and fill | % |
| %GLP | General longitudinal profile | % |
| %MNT | Length of road in mountainous terrain as a percentage of road length | % |
| %RCK | Volume of rocky soil as a percentage of volume of soil | % |
| %URB | Length of the road project crossing urban areas as a percentage of road length | % |
| %VET | Volume of embankment treatment | % |
| %WDB | Number of bridges to be widened as a percentage of number of bridges | % |
| CBR | California Bearing Ratio | % |
| EAL | Equivalent standard axle (8.2t) loading—ESAL | u |
| ECS | Existing cross section | m |
| ILCT1 | Initial land cover type I | list |
| ILCT1% | % of project alignment covered with initial land cover type I | % |
| ILCT2 | Initial land cover type II | list |
| ILCT2% | % of project alignment covered with initial land cover type II | % |
| L | Road project length | m |
| LW | Lane width | m |
| MW | Median width | m |
| MT | Median type | list |
| NBL | Number of lanes | u |
| OST | Overlay structure type | list |
| PST | Pavement structure type | list |
| RTP | Road type | list |
| STH | Area where subgrade has to be treated with hydraulic binders | % |
| SW | Shoulder width | m |
| TBM | Type of barrier material | list |
| TSB | Type of structure (standard bridges) | list |
| TSM | Type of structure (major bridges) | list |
| TSW | Type of structure (wall) | list |
| TUN | Length of tunnel | m |
| WTP | Works type | list |

## GHG Generators

This chapter focuses on ROADEO's Stage 2 output—identification of GHG generators, based on the quantities of works for various components of the road project as defined in Stage 1.

### Materials

The ROADEO calculator focuses on the following main materials (currently) including:

- granular materials,
- hydraulic binder treated materials (currently including cement and lime),
- bitumen-treated materials,
- metals (copper, steel),
- rammed soil, and
- timber.

#### Earthworks

For earthworks, materials do not represent a significant input, except for hydraulic binders (which can be a major contributor).

**MHB** = STH x SGP x 0.3 x 0.05 + VET x 0.02

Where

MHB: Mass of hydraulic binder (in t)

STH: Area where subgrade has to be treated with hydraulic binders (as a % of subgrade preparation area)

SGP: Area of subgrade preparation (in m²)

VET: Volume of embankment to be treated (in m³)

This assumes treatment of:

- the required area over a thickness of 30 cm, for a soil density of 2t/m³ and for a hydraulic binder proportion of 2.5 percent, and
- the required volume of embankment, for a soil density of 2t/m³ and for a hydraulic binder (lime) proportion of 1 percent.

The quantity and binder type can be adjusted manually by the user to reflect other conditions (treatment thickness, proportion of binder).

Soil densities can be considered as shown in table B5.

**TABLE B5 SOIL DENSITIES FOR BINDER MIXING WITH SOIL**

| Materials dry density (t/m³) | Min | Max |
|---|---|---|
| Silt | 1.6 | 1.8 |
| Clay | 1.7 | 1.8 |
| **Sand** | | |
| Homometric sand | 1.4 | 1.6 |
| Graduated sand | 1.6 | 1.9 |
| Granular soil | 1.8 | 2.2 |

Other binders can be considered (either as an alternative or as a combined solution, for example, treatment with 3 percent lime and 2 percent cement), with the emissions factors in table B6.

#### Pavement

New Pavement

The model considers six types of pavement structures (table B7). For each of these, a pavement catalogue has been used.

The materials in table B8 have been considered.

**TABLE B6 EMISSION FACTORS OF HYDRAULIC BINDERS**

| Binder | $CO_2$ impact (kg $CO_2$ eq./t) | Source |
|---|---|---|
| Cement CEM I | 868 | ATILH |
| Cement CEM II | 650 | ATILH |
| Hydraulic road binder HRB 70% slag | 294 | ATILH |
| Hydraulic road a HRB 50% slag | 459 | ATILH |
| Hydraulic road binder HRB 30% slag | 625 | ATILH |
| Hydraulic road binder HRB 30% limestone | 614 | ATILH |
| Hydraulic road binder HRB 30% fly ash | 613 | ATILH |
| Quicklime | 1,059 | Union of Lime Producers (France) |

*Notes:*
ATILH—Association Technique de l'Industrie des Liants Hydrauliques (Technical Association of Hydraulic Binders Industry.
Percentage of binder in volume.

**TABLE B7 TYPICAL PAVEMENT TYPES AND DESIGNS**

| Pavement type (PST) | Catalogue used |
|---|---|
| Concrete pavement | California Department of Transportation Highway Design Manual, Tables 623 F and 623G |
| Bituminous pavement on granular materials | Transport Research Laboratory Road Note 31, Charts 3 and 5 |
| Bituminous pavement on hydraulic bound materials | Transport Research Laboratory Road Note 31, Chart 4 |
| Bituminous pavement on bituminous bound materials | Transport Research Laboratory Road Note 31, Chart 7 |
| Surface dressing | Transport Research Laboratory Road Note 31, Chart 1 |
| Gravel | Transport Research Laboratory Road Note 31, Chart 1 |

The ROADEO calculator requires the following input from the user:

- Traffic data, in ESAL (106 equivalent standard axles to 8.16t); and
- Surface strength, as a CBR result.

Data are then converted according to the following tables, to find the corresponding pavement layer types and thicknesses in the above catalogues.

For concrete pavement, see tables B9 and B10. For all other structures, see tables B11 and B12.

If CBR Values are not available, the Overseas Road Note provides table B13 (p. 52).

Quantities of material are then calculated according to the following table, depending on the type of works (in the formulas, Ti is the thickness of type i resulting from the above catalogue consideration).

**TABLE B8 MATERIALS CONSIDERED IN TYPICAL PAVEMENT DESIGNS**

| Material | Reference |
|---|---|
| Double surface dressing | Transport Research Laboratory Road Note 31 |
| Flexible bituminous surface | |
| Bituminous surface (usually a wearing course WC and a base course BC) | |
| Bituminous road base, RB | |
| Granular road base, GB1–GB6 | |
| Granular subbase, GS | |
| Granular capping layer or selected subgrade fill, GC | |
| Cement- or lime-stabilized road base 1, CB4 | |
| Cement- or lime-stabilized road base 2, CB5 | |
| Cement- or lime-stabilized subbase, CS | |
| Concrete with dowels, JPCP | California Department of Transportation Highway Design Manual, Tables 623 F and 623G |
| Concrete (lean concrete), LCB | |

**TABLE B9 TRAFFIC CLASSES FOR CONCRETE PAVEMENT**

| $TI=9x(ESA\ 8t/10^6)^{0.119}$ | Traffic indexes |
|---|---|
| 0.0 | TI1 |
| 9.5 | TI2 |
| 10.5 | TI3 |
| 11.5 | TI4 |
| 12.5 | TI5 |
| 13.5 | TI6 |
| 14.5 | TI7 |
| 15.5 | TI8 |
| 16.5 | TI9 |
| 17.0 | TI10 |

**TABLE B10 SUBGRADE CLASS FOR CONCRETE PAVEMENT STRUCTURES**

| CBR (%) | Subgrade classes |
|---|---|
| 40 | Type 1 |
| 10 | Type 2 |

**TABLE B11 TRAFFIC CLASSES FOR ALL PAVEMENT STRUCTURES EXCEPT CONCRETE**

| ESA (8.16) (x106) | Traffic classes (ORN 31) |
|---|---|
| 0.3 | T1 |
| 0.7 | T2 |
| 1.5 | T3 |
| 3 | T4 |
| 6 | T5 |
| 10 | T6 |
| 17 | T7 |
| 30 | T8 |

Quantities of each layer are then converted into quantities of basic materials as per table B14.

For both asphalt and concrete, quantities of basic materials are then calculated on the basis of the percentages in table B15:

In rehabilitations, it is considered that the only works conducted consist of the application of an overlay on the existing pavement (see section 1.2.2 Overlay). Hence, quantities of new pavement are nil. Similarly, for a widening, an overlay is applied on the existing cross-section, and the calculated pavement structure is applied only on the new pavement area. That is why the factor (1-POA) is applied to all of the formulas in the aforementioned table B14.

For both types of work (rehabilitation and widening), the quantities of overlay are calculated as follows.

### Overlay

Three types of overlay have been considered: bituminous, surface dressing, and gravel. These are addressed by the parameter OST, overlay structure type.

**VBO** = POA x 0.12 if OST = bituminous

Where

VBO**:** Volume of bituminous concrete for overlay (in $m^3$)

POA: Area of pavement overlay (in $m^2$)

Assumed thickness is 12 cm for material type 2 of new pavement catalogue.

**TABLE B12 SUBGRADE CLASS FOR ALL PAVEMENT STRUCTURES EXCEPT CONCRETE**

| CBR (%) | Subgrade classes (ORN 31) | Comments |
|---|---|---|
| 2 | S1 | Poor soil: Contains appreciable amounts of clay and fine silt. (50 percent or more passing -200) P.I. over .20 |
| 5 | S2 | |
| 8 | S3 | Normal soil: Retains a moderate degree of firmness under adverse moisture conditions. Loams, salty sands, sand gravels with moderate amounts of clay, and fine silt. P.I. 15–20 |
| 15 | S4 | |
| 30 | S5 | Good soil: Retains a substantial amount of load bearing capacity when wet. Sands, sand gravels, materials free of detrimental amounts of plastic material. P.I. less than 15 |
| >30 | S6 | |

**TABLE B13 SUBGRADE STRENGTH CLASSES USED WHEN CALIFORNIA BEARING RATIO DATA ARE UNAVAILABLE**

| Depth of water table from formation level (meters) | Subgrade strength class | | | | |
|---|---|---|---|---|---|
| | Non-plastic | Sandy clay PI*=10 | Sandy clay PI*=20 | Silty clay PI*=30 | Heavy clay PI*>40 |
| 0.5 | S4 | S4 | S2 | S2 | S1 |
| 1 | S5 | S4 | S3 | S2 | S1 |
| 2 | S5 | S5 | S4 | S3 | S2 |
| 3 | S6 | S5 | S4 | S3 | S2 |

*PI=Plasticity Index

*Note:* Overseas Road Notes are prepared principally for road and transport authorities in countries receiving technical assistance from the British government.

## TABLE B14 QUANTITIES OF MATERIALS FOR TYPICAL PAVEMENT LAYERS

| | Layer definitions | Unit | Calculation | |
|---|---|---|---|---|
| | | | New alignment | Widening |
| 1 | Double surface dressing | $m^2$ | (NBL*LW)*L* T1 (1) | ((NBL*LW)-POA)*L* T1 |
| 2 | Flexible bituminous surface | $m^3$ | (NBL*LW+2*0.8*A8+A9+0.30)*L*T2/1000 | ((NBL*LW+2*0.8*A8+A9+0.30) - POA)*L*T2/1000 |
| 3 | Bituminous surface (usually a wearing course WC and a base course BC) | $m^3$ | (NBL*LW+2*0.8*A8+A9+0.30)*L*T3/1000 | ((NBL*LW+2*0.8*A8+A9+0.30) - POA)*L*T3/1000 |
| 4 | Bituminous road base, RB | $m^3$ | (NBL*LW+SW*2+MW+0.50)*L*T4/1000 | ((NBL*LW+SW*2+MW+0.50)–POA)*L*T4/1000 |
| 5 | Granular road base, GB1 - GB6 | $m^3$ | (NBL*LW+SW*2+MW+0.50)*L*T5/1000 | ((NBL*LW+SW*2+MW+0.50)–POA)*L*T5/1000 |
| 6 | Granular subbase, GS | $m^3$ | (NBL*LW+SW*2+MW+0.50)*L*T6/1000 | ((NBL*LW+SW*2+MW+0.50)–POA)*L*T6/1000 |
| 7 | Granular capping layer or selected subgrade fill, GC | $m^3$ | (NBL*LW+SW*2+MW+0.50)*L*T7/1000 | ((NBL*LW+SW*2+MW+0.50–POA)*L*T7/1000 |
| 8 | Cement- or lime-stabilized road base 1, CB4 | $m^3$ | (NBL*LW+SW*2+MW+0.50)*L*T8/1000 | ((NBL*LW+SW*2+MW+0.50)–POA)*L*T8/1000 |
| 9 | Cement- or lime-stabilized road base 2, CB5 | $m^3$ | (NBL*LW+SW*2+MW+0.50)*L*T9/1000 | ((NBL*LW+SW*2+MW+0.50)–POA)*L*T9/1000 |
| 10 | Cement- or lime-stabilized subbase, CS | $m^3$ | (NBL*LW+SW*2+MW+0.50)*L*T10/1000 | ((NBL*LW+SW*2+MW+0.50)–POA)*L*T10/1000 |
| 11 | Concrete with dowels, JPCP | $m^3$ | (NBL*LW+2*0.8*A8+A9+0.30)*L*T11/1000 | ((NBL*LW+2*0.8*A8+A9+0.30)–POA)*L*T11/1000 |
| 12 | Concrete (lean concrete), LCB | $m^3$ | (NBL*LW+SW*2*+MW+0.50)*L*T12/1000 | ((NBL*LW+SW*2*+MW+0.50)–POA)*L*T12/1000 |

*Notes:*

(1): The double surface-dressing value from the catalogue has no thickness and is just equal to 1 when it is present, and 0 otherwise.

(2): Thicknesses are expressed in mm in the catalogue

Where:

A8=Shoulder width if shoulders are paved, and 0 otherwise;

A9=Median width if the median lane is paved, and 0 otherwise; and

POA=Pavement Overlay Area ($m^2$).

**TABLE B15 COMPOSITION OF PAVEMENT LAYERS (percent in volume)**

| Layer | Bituminous emulsion | Quarried aggregate | Asphalt general | Soil general (rammed soil) | Cement general (typical) | Concrete road & pavement | Steel |
|---|---|---|---|---|---|---|---|
| Layer 1 | 9 | 91 | 0 | 0 | 0 | 0 | 0 |
| Layer 2 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| Layer 3 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| Layer 4 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| Layer 5 | 0 | 100 | 0 | 0 | 0 | 0 | 0 |
| Layer 6 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Layer 7 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Layer 8 | 0 | 94 | 0 | 0 | 6 | 0 | 0 |
| Layer 9 | 0 | 96 | 0 | 0 | 4 | 0 | 0 |
| Layer 10 | 0 | 0 | 0 | 98 | 2 | 0 | 0 |
| Layer 11 | 0 | 0 | 0 | 0 | 0 | 92 | 8 |
| Layer 12 | 0 | 0 | 0 | 0 | 0 | 100 | 0 |

**TABLE B16 COMPOSITION OF ASPHALT AND CONCRETE (percent)**

| Layer | Bitumen | Cement general (typical) | Quarried aggregate | Sand |
|---|---|---|---|---|
| Concrete | | 7.10 | 31.75 | 45.70 |
| Asphalt concrete | 5 | 0 | 95.00 | 0 |

**ASO** = POA if OST = surface dressing

Where

AST: Area of surface dressing for overlay (in $m^2$)

POA: Area of pavement overlay (in $m^2$)

for material type 1 of new pavement catalogue.

**VGO** = POA x 0.2 if OST = gravel

Where

VGO: Volume of gravel for re-gravelling (in $m^3$)

POA: Area of pavement overlay (in $m^2$)

for material type 5 of new pavement catalogue.

### Other Roads

For other roads, the calculation for new pavement is used, based on 30 percent of the ESAL of the main road, the same pavement structure type, and the same CBR.

The quantities of materials can be calculated by multiplying by the values of OPR resulting from Stage 1.

### Drainage

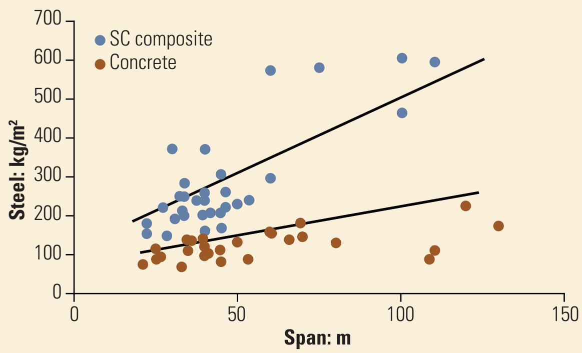
For drainage, the main GHG contribution results from the use of reinforced concrete or masonry for the construction of drains and culverts.

The quantities of materials (represented in tons of steel or $m^3$ of concrete per linear meter of drainage type) can be directly calculated by multiplying the above ratios by LPC, LBC, and LLD resulting from Stage 1.

**TABLE B17 QUANTITIES OF MATERIALS FOR DRAINAGE WORKS**

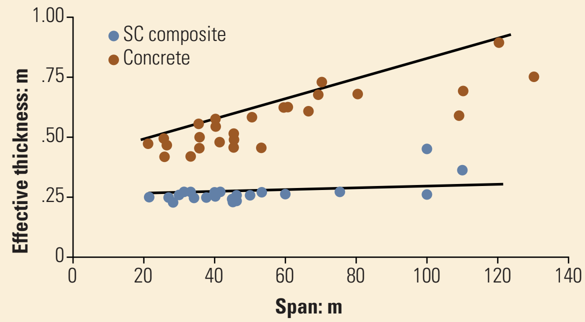
| Material structure | Steel | Concrete |
|---|---|---|
| Lined drains | 0.019 t/m | 0.27 $m^3$/m |
| Pipe culverts | 0.018 t/m | 0.22 $m^3$/m |
| Box culverts | 0.145 t/m | 1.4 $m^3$/m |

**FIGURE B2 QUANTITIES OF STEEL (KG/M²) FOR BRIDGES, DEPENDING ON SPAN**




*Source:* D. Collings, *Bridge Engineering*, Vol. 159, December 2006, Issue BE4, pp. 163–168.

**FIGURE B3 EFFECTIVE THICKNESS—THUS QUANTITIES OF CONCRETE—FOR BRIDGES, DEPENDING ON SPAN**




*Source:* D. Collings, *Bridge Engineering*, Vol. 159, December 2006, Issue BE4, pp. 163–168.

**TABLE B18 QUANTITIES OF MATERIALS FOR WALLS**

| Quantity of material<br>Type of wall | Steel | Concrete | Rammed soil |
|---|---|---|---|
| Steel | 0.108 t/m² | | |
| Reinforced concrete | 0.045 t/m² | 0.40 m³/m² | |
| Reinforced earth | 0.012 kg/m² | 0.07 m³/m² | 1.5 m³/m² |

*Note:* Quantities provided in mass of steel or volume of concrete or rammed soil per area of wall.

### Structures

The main materials considered for structures are steel and concrete.

The following charts have been used for bridges, extracted from “An environmental comparison of bridge forms.” D. Collings, *Bridge Engineering*, Vol.159, December 2006, Issue BE4, Pg 163–168.

Three parameters are required for this stage.

1. TSW: Type of structure (wall), which can be
   - steel (sheetpile),
   - reinforced concrete, or
   - reinforced earth.
2. TSB: type of structure (standard bridges), which can be
   - composite (steel/concrete), or
   - concrete (reinforced/prestressed).
3. TSM: type of structure (major bridges), which can be
   - composite (steel/concrete),
   - concrete (reinforced/prestressed), or
   - steel.

It has been assumed that tunnels are constructed with a concrete lining.

### Walls

The quantities of materials can be directly calculated by multiplying the above ratios by WAL after the selection of TSW.

Quantity of concrete is then divided into basic material as indicated in table B17.

### Standard bridges

The quantities of materials can be directly calculated by multiplying the above ratios by the sum of SBA and IBA after the selection of TSB.

**TABLE B19 QUANTITIES OF MATERIALS FOR STANDARD BRIDGES**

| Quantity of material<br>Type of structure | Steel | Concrete |
|---|---|---|
| Composite | 0.220 t/m² | 0.30 m³/m² |
| Concrete | 0.115 t/m² | 0.5 m³/m² |

**TABLE B20 QUANTITIES OF MATERIALS FOR MAJOR BRIDGES**

| Quantity of material<br>Type of structure | Steel | Concrete |
|---|---|---|
| Steel | 0.650 t/m² | 0.15 m³/m² |
| Composite | 0.518 t/m² | 0.35 m³/m² |
| Concrete | 0.225 t/m² | 0.85 m³/m² |

*Note:* Quantities provided in tons of steel or cubic meters of concrete per area of bridge deck.

Quantity of concrete is then divided into basic material as indicated in table B17.

### Major bridges

An average span of 125 m has been considered.

The quantities of materials can be directly calculated by multiplying the above ratios by MBA after the selection of TSM.

Quantity of concrete is then divided into basic material as indicated in table B17.

### Tunnel

The temporary and permanent lining of the tunnel have been assumed to be of concrete, with reinforcement or steel arches.

The quantities of materials can be directly calculated by multiplying the above ratios by TLV.

Quantity of concrete is then divided into basic material as indicated in table B17.

## Equipment and Road Furniture

### Barriers

For barriers, the parameter TBM (type of barrier material) is considered, which can be steel or timber (except on national roads and expressways).

**TABLE B21 QUANTITIES OF MATERIALS FOR TUNNELS**

| Material | Quantity |
|---|---|
| Steel | 0.14 t/m³ |
| Concrete | 1 m³/m³ |

*Note:* Quantities provided in tons of steel or cubic meters of concrete per volume of tunnel.

**TABLE B22 QUANTITIES OF MATERIALS FOR BARRIERS**

| Quantity of material<br>Type of structure | Timber | Steel | Concrete |
|---|---|---|---|
| Steel | | 0.012 t/m | |
| Concrete | | 0.002 t/m | 0.25 m³/m |
| Timber | 0.019 t/m | 0.008 t/m | |

*Note:* Quantities provided in tons of timber or steel or cubic meters of concrete per linear metre of barrier.

The quantities of materials can be directly calculated by multiplying the above ratios by LBR once TBM has been selected.

Quantity of concrete (if any) is then divided into basic material as indicated in table B17.

### Signs

Police signs and their supports are assumed to be in galvanized steel. Signs are supposed to be 0.8 m², 3mm thick, with a 2.5m high support of 6 kg/m.

The quantity of galvanized steel for police signs is therefore assumed as 35 kg/unit, and can be directly calculated from the value of NPS resulting from Stage 1.

Directional signs are supposed to be supported by steel (steel pole, except for expressways, where they are gantries). The quantities in table B23 are given for 1 m² of directional sign.

**TABLE B23 QUANTITIES OF MATERIALS FOR DIRECTIONAL SIGNS**

| Type of road | Quantity of steel for support | Quantity of steel for sign | Total quantity of steel | Quantity of concrete |
|---|---|---|---|---|
| Expressway | 0.070 t/m² | 0.025 t/m² | 0.095 t/m² | 0.3 m³/m² |
| National/provincial/rural | 0.018 t/m² | | 0.043 t/m² | 0.2 m³/m² |

*Note:* Quantities provided in tons of timber or steel or cubic meters of concrete per square metre of sign.

Concrete for foundation is not taken into account. Aluminum has not been taken into account, although it is used in several countries for supports and sign panels.

The quantities of materials can be calculated directly by multiplying the above ratios by DSA resulting from Stage 1, based on road type (RTP).

Quantity of concrete is then divided into basic material as indicated in table B17.

### Lighting

Materials are calculated for 15m-high steel supports and for the power cable (50m for one pole).

The quantities of materials can be calculated directly by multiplying the above ratios by NSL resulting from Stage 1.

Quantity of concrete is then divided into basic material as indicated in table B17.

### Wayside Amenities

Materials are concrete (for pavement and buildings), steel (for buildings) and bituminous materials (for pavement).

For pavement, the calculation is made for the same structure as for the pavement of the main section for the WPA area.

For buildings, materials have been assumed to be steel and concrete (reinforced concrete).

The quantities of materials can be calculated directly by multiplying the above ratios by WBA resulting from Stage 1.

Quantity of concrete is then divided into basic material as indicated in table B17.

## Works Equipment

The following characteristics have been considered for works equipment.

The information in table B27 (pp. 61–64) has been used to derive the following ratios/default values.

## Transport

### Distances

The distances in table B27 (p. 61) have been considered.

### Fleet Vehicles

Road transport has been assumed by default.

A suboptimal use of transport fleet has also been assumed, involving the use of some medium trucks (15 percent) for long distance transport (over 25 km).

Although they are believed to reflect general actual conditions, these are important assumptions. They are not optimal and may trigger suggestions to use alternatives. Therefore, the user may have to check and adjust them.

In the 25–50 km range, only 11–19 ton diesel trucks were considered.

**TABLE B24 QUANTITIES OF MATERIALS FOR LIGHTING WORKS**

| Quantity of steel for support | Quantity of concrete | Copper |
|---|---|---|
| 0.420 t/u | 0.6 $m^3$/u | 0.0225 t/u |

*Note:* Quantities provided in cubic meters of concrete or tons of copper per number of lights.

**TABLE B25 QUANTITIES OF MATERIALS FOR WAYSIDE AMENITIES**

| Quantity of steel | Quantity of concrete |
|---|---|
| 0.08 t/$m^2$ | 0.55 $m^3/m^2$ |

*Note:* Quantities provided in tons of steel or cubic meters of concrete per square meter of wayside amenity.

**TABLE B26 CHARACTERISTICS OF CONSTRUCTION EQUIPMENT**

| Equipment | Works components | Type of road | Capacity | Capacity unit | Data source for capacity | Consumption/ hour | Consumption unit | Data source for consumption | Emission factor (kg $CO_2$ eq./Hr) |
|---|---|---|---|---|---|---|---|---|---|
| Aggregate crushing plant | Pavement; Structures; Drainage | Expressway | 115 | $m^3$/hr | Shanghai Zenith Company | 145 | Liters/hr | IVL Report | 426.89 |
| | | National road | 70 | $m^3$/hr | | 87 | Liters/hr | IVL Report | 256.07 |
| | | Provincial road | 46 | $m^3$/hr | | 58 | Liters/hr | IVL Report | 170.52 |
| | | Rural road | 23 | $m^3$/hr | | 29 | Liters/hr | IVL Report | 85.26 |
| Aggregate crushing plant (electricity) | Pavement; Structures; Drainage | Expressway | 115 | $m^3$/hr | Shanghai Zenith Company | 11,454 | KW | IVL Report | depending on country |
| | | National road | 70 | $m^3$/hr | | 6,872 | KW | IVL Report | |
| | | Provincial road | 46 | $m^3$/hr | | 4,582 | KW | IVL Report | |
| | | Rural road | 23 | $m^3$/hr | | 2,291 | KW | IVL Report | |
| Asphalt mixing plant | Pavement | Expressway | 50 | $m^3$/hr | | 10,480 | KW | IVL Report | depending on country |
| | | National road | 35 | $m^3$/hr | | 7,336 | KW | IVL Report | |
| | | Provincial road | 20 | $m^3$/hr | | 4,192 | KW | IVL Report | |
| Asphalt paver | Pavement | Expressway; National road | 1,300 | $m^2$/hr | IVL Report | 22 | Liters/hr | IVL Report | 64.68 |
| | | Provincial road | 1,200 | $m^2$/hr | IVL Report | 20 | Liters/hr | IVL Report | 58.80 |
| Backhoe loader | Pavement | All roads | 520 | $m^3$/hr | IVL Report | 16 | Liters/hr | IVL Report | 47.04 |
| Bitumen sprayer | Pavement | Expressway; National road | 22,800 | $m^2$/hr | IVL Report | 3 | Liters/hr | IVL Report | 8.82 |
| | Pavement | Provincial road; Rural road | 19,125 | $m^2$/hr | IVL Report | 3 | Liters/hr | IVL Report | 8.82 |
| Bulldozer | Earthworks | Expressway; National road, Provincial road | 500 | $m^3$/hr | Caterpillar | 25 | Liters/hr | Caterpillar | 73.50 |
| Soil compactor | Earthworks; Pavement | Expressway; National road | 1,006 | $m^2$/hr | IVL Report | 18 | Liters/hr | IVL Report | 52.92 |
| | | Provincial road; Rural road | 791 | $m^2$/hr | IVL Report | 12 | Liters/hr | IVL Report | 35.28 |
| Asphalt compactor | Pavement | Expressway; National road | 791 | $m^2$/hr | IVL Report | 18 | Liters/hr | IVL Report | 52.92 |
| | | Provincial road; Rural road | 460 | $m^2$/hr | IVL Report | 7 | Liters/hr | IVL Report | 19.70 |
| Tower Crane (small) | Structures | Expressway; National road | N/A | $m^2$/hr | IVL Report | 9 | Liters/$m^2$ | IVL Report | 30.61 kg $CO_2$ eq./$m^2$ |

**(continued)**

**TABLE B26 CONTINUED**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tower Crane (big) | Structures | Provincial road; Rural road | N/A | | $m^2$/hr | IVL Report | 16 | Liters/$m^2$ | IVL Report | 55.66 kg $CO_2$ eq./$m^2$ |
| Tower Crane (small) | Structures | Expressway; National road | N/A | | $m^2$/hr | IVL Report | 4 | Liters/$m^2$ | IVL Report | 15.30 kg $CO_2$ eq./$m^2$ |
| Tower Crane (big) | Structures | Provincial road; Rural road | N/A | | $m^2$/hr | IVL Report | 8 | Liters/$m^2$ | IVL Report | 27.83 kg $CO_2$ eq./$m^2$ |
| Drilling machine | Structures | Expressway; National road | N/A | | $m^3$ | IVL Report | 1,339 | Liters/$m^3$ | IVL Report | 4.59 kg $CO_2$ eq./$m^3$ |
| Drilling machine | Structures | Provincial road; Rural road | N/A | | $m^3$ | IVL Report | 2,434 | Liters/$m^3$ | IVL Report | 8.35 kg $CO_2$ eq./$m^3$ |
| Dumper | Earthworks; Pavement | All roads | flat | 140 | $m^3$/h*km | IVL Report | 20 | Liters/hr | IVL Report | 58.80 |
| Dumper | Earthworks; Pavement | All roads | broken | 140 | $m^3$/h*km | IVL Report | 28 | Liters/hr | IVL Report | 80.85 |
| Dumper | Earthworks; Pavement | All roads | hilly | 140 | $m^3$/h*km | IVL Report | 35 | Liters/hr | IVL Report | 102.90 |
| Excavator (< 5% stones) | Earthworks | All roads | 450 | | $m^3$/hr | IVL Report | 34 | Liters/hr | IVL Report | 99.96 |
| Excavator (< 25% stones) | Earthworks | All roads | 430 | | $m^3$/hr | IVL Report | 34 | Liters/hr | IVL Report | 99.96 |
| Excavator (< 50% stones) | Earthworks | All roads | 360 | | $m^3$/hr | IVL Report | 34 | Liters/hr | IVL Report | 99.96 |
| Excavator (> 50% stones) | Earthworks | All roads | 300 | | $m^3$/hr | IVL Report | 34 | Liters/hr | IVL Report | 99.96 |
| Excavator (hydraulic) | Pavement; Structures; Drainage | All roads | 360 | | $m^3$/hr | IVL Report | 45 | Liters/hr | IVL Report | 132.30 |
| Motor grader | Earthworks; Pavement | Expressway; National road | 15,385 | | $m^2$/hr | Caterpillar | 42 | Liters/hr | Caterpillar | 123.48 |
| | | Provincial road; Rural road | 14,240 | | $m^2$/hr | Caterpillar | 35 | Liters/hr | Caterpillar | 102.90 |
| Hydraulic hammer | Earthworks | All roads | 40 | | $m^3$/hr | IVL Report | 18 | Liters/hr | IVL Report | 52.92 |

**(continued)**

**TABLE B26 CONTINUED**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wheeled loader (< 5% stones) | Earthworks | All roads | 520 | $m^3$/hr | IVL Report | 23 | Liters/hr | IVL Report | 67.62 |
| Wheeled loader (< 25% stones) | Earthworks | All roads | 470 | $m^3$/hr | IVL Report | 23 | Liters/hr | IVL Report | 67.62 |
| Wheeled loader (< 50% stones) | Earthworks | All roads | 410 | $m^3$/hr | IVL Report | 35 | Liters/hr | IVL Report | 102.90 |
| Wheeled loader (> 50% stones) | Earthworks | All roads | 370 | $m^3$/hr | IVL Report | 35 | Liters/hr | IVL Report | 102.90 |
| Pile driver | Structures | Expressway; National road | N/A | $m^2$/hr | IVL Report | 1.339 | Liters/$m^2$ | IVL Report | 4.59 kg $CO_2$ eq./$m^2$ |
| Pile driver | Structures | Provincial road; Rural road | N/A | $m^2$/hr | IVL Report | 1.607 | Liters/$m^2$ | IVL Report | 5.51 kg $CO_2$ eq./$m^2$ |
| Pulvimixer | Earthworks | Expressway; National road | 9,173 | $m^2$ /hr | Caterpillar | 46 | Liters/hr | Caterpillar | 135.24 |
| Aggregate spreader | Pavement | Rural road (Surface treatment) | 19,125 | $m^2$/hr | IVL Report | 20 | Liters/hr | IVL Report | 58.80 |
| Slipform paver | Pavement; Structures; Drainage | Expressway; National road; Provincial road | N/A | $m^3$/hr | IVL Report | 0.025 | Liters/$m^3$ | IVL Report | 0.086 kg $CO_2$ eq./$m^3$ |
| Slipform for Barrier | Equipment (barriers) | Expressway; National road | N/A | m/hr | IVL Report | 0.009 | Liters/m | IVL Report | 0.031 kg $CO_2$ eq./m |
| Water sprayer | Earthworks; Pavement | All roads | 40,000 | $m^2$/hr | IVL Report | 27 | Liters/hr | IVL Report | 79.38 |

**TABLE B27 EMISSIONS DUE TO EQUIPMENT FOR VARIOUS WORKS TYPES**

| Works item | Unit | Equipment | Unit consumption (l/qty) | |
|---|---|---|---|---|
| | | | Exp/Nat | Prov/Rural |
| **Earthworks** | | | | |
| Clearing and grubbing | $m^2$ | Bulldozer | 0.083 | 0.083 |
| Cut | $m^3$ | Excavator (< 5% stones) | 0.076 | 0.076 |
| | $m^3$ | Excavator (< 25% stones) | 0.079 | 0.079 |
| | $m^3$ | Excavator (< 50% stones) | 0.094 | 0.094 |
| | $m^3$ | Excavator (> 50% stones) | 0.113 | 0.113 |
| Reuse of hard rock as pavement layer | $m^3$ | Aggregate crushing plant | 0.652 | 0.652 |
| Reuse of hard rock as fill | $m^3$ | Aggregate crushing plant | 0.652 | 0.652 |
| Reuse of soil as fill | $m^3$ | Dumper | 0.143 | 0.071 |
| | $m^3$ | Backhoe loader (*2) | 0.062 | 0.062 |
| Fill from borrow pit | $m^3$ | Excavator (< 5% stones) | 0.076 | 0.076 |
| | $m^3$ | Backhoe loader | 0.031 | 0.031 |
| Evacuation of soil | $m^3$ | Backhoe loader | 0.031 | 0.031 |
| Preparation of subgrade | $m^2$ | Motor grader | 0.003 | 0.002 |
| | $m^2$ | Water sprayer | 0.001 | 0.001 |
| | $m^2$ | Soil compactor | 0.030 | 0.030 |
| Embankment treatment | $m^3$ | Pulvimixer | 0.005 | 0.005 |
| | $m^3$ | Water sprayer | 0.001 | 0.001 |
| | $m^3$ | Binder spreader | 0.000 | 0.000 |
| Subgrade treatment | $m^3$ | Pulvimixer | 0.005 | 0.005 |
| | $m^3$ | Water sprayer | 0.001 | 0.001 |
| | $m^3$ | Binder spreader | 0.000 | 0.000 |
| **Pavement** | | | | |
| Double surface dressing | $m^3$ | Bitumen sprayer | 0.030 | 0.030 |
| | $m^3$ | Aggregate spreader | 0.030 | 0.030 |
| | $m^3$ | Soil compactor | 2.865 | 2.865 |
| Flexible bituminous surface | $m^3$ | Asphalt mixing plant | 5.989 | 5.989 |
| | $m^3$ | Asphalt paver | 0.340 | 0.340 |
| | $m^3$ | Asphalt compactor | 0.460 | 0.300 |
| Bituminous surface | $m^3$ | Asphalt mixing plant | 5.989 | 5.989 |
| | $m^3$ | Asphalt paver | 0.142 | 0.142 |
| | $m^3$ | Asphalt compactor | 0.192 | 0.125 |
| Bituminous road base, RB | $m^3$ | Asphalt mixing plant | 5.989 | 5.989 |
| | $m^3$ | Motor grader | 0.020 | 0.013 |
| | $m^3$ | Asphalt compactor | 0.153 | 0.100 |

**(continued)**

**TABLE B27 CONTINUED**

| Works item | Unit | Equipment | Unit consumption (l/qty) | |
|---|---|---|---|---|
| | | | Exp/Nat | Prov/Rural |
| Granular road base, GB1–GB6 | $m^3$ | Motor grader | 0.017 | 0.011 |
| | $m^3$ | Water sprayer | 0.004 | 0.004 |
| | $m^3$ | Soil compactor | 0.171 | 0.171 |
| Granular subbase, GS | $m^3$ | Motor grader | 0.013 | 0.009 |
| | $m^3$ | Water sprayer | 0.003 | 0.003 |
| | $m^3$ | Soil compactor | 0.133 | 0.133 |
| Granular capping layer or selected subgrade fill, GC | $m^3$ | Motor grader | 0.015 | 0.010 |
| | $m^3$ | Soil compactor | 0.150 | 0.150 |
| Cement- or lime-stabilized road base 1, CB4 | $m^3$ | Pulvimixer | 0.040 | 0.040 |
| | $m^3$ | Water sprayer | 0.006 | 0.006 |
| | $m^3$ | Motor grader | 0.024 | 0.016 |
| | $m^3$ | Soil compactor | 0.240 | 0.240 |
| Cement- or lime-stabilized road base 2, CB5 | $m^3$ | Pulvimixer | 0.033 | 0.033 |
| | $m^3$ | Water sprayer | 0.005 | 0.005 |
| | $m^3$ | Motor grader | 0.020 | 0.013 |
| | $m^3$ | Soil compactor | 0.200 | 0.200 |
| Cement- or lime-stabilized subbase, CS | $m^3$ | Pulvimixer | 0.000 | 0.000 |
| | $m^3$ | Water sprayer | 0.000 | 0.000 |
| | $m^3$ | Motor grader | 0.000 | 0.000 |
| | $m^3$ | Soil compactor | 0.000 | 0.000 |
| Concrete with dowels, JPCP | $m^3$ | Concrete batching plant | 1.682 | 1.682 |
| | $m^3$ | Slipform paver | 0.101 | 0.101 |
| Concrete (lean concrete), LCB | $m^3$ | Concrete batching plant | 1.682 | 1.682 |
| | $m^3$ | Slipform paver | 0.153 | 0.153 |
| Excavation of soil general (rammed soil) for subbase layers | $m^3$ | Excavator (< 5% stones) | 0.030 | 0.030 |
| | $m^3$ | Backhoe loader | 0.030 | 0.030 |
| Surface dressing overlay | $m^3$ | Bitumen sprayer | 0.030 | 0.030 |
| | $m^3$ | Aggregate spreader | 0.030 | 0.030 |
| | $m^3$ | Soil compactor | 2.865 | 2.865 |
| Asphalt concrete overlay | $m^3$ | Asphalt mixing plant | 5.989 | 5.989 |
| | $m^3$ | Asphalt paver | 0.142 | 0.142 |
| | $m^3$ | Asphalt compactor | 0.192 | 0.125 |
| Re-gravelling | $m^3$ | Motor grader | 0.015 | 0.010 |
| | $m^3$ | Soil compactor | 0.150 | 0.150 |
| Bituminous coating | $m^2$ | Emulsion applier | 0.000 | 0.000 |

**(continued)**

**TABLE B27 CONTINUED**

| Works item | Unit | Equipment | Unit consumption (l/qty) | |
|---|---|---|---|---|
| | | | Exp/Nat | Prov/Rural |
| **Drainage** | | | | |
| Lined/earth/pipe longitudinal drain | m | Excavator | 0.045 | 0.011 |
| Box culverts | m | Excavator | 2.267 | 1.133 |
| Concrete for lined drains/box culverts | $m^3$ | Concrete batching plant | 1.682 | 1.682 |
| **Structures** | | | | |
| Walls | $m^2$ | Pile driver | 1.339 | 1.607 |
| Concrete for walls (reinforced concrete) | $m^3$ | Concrete batching plant | 1.682 | 1.682 |
| | $m^3$ | Concrete pump—small | 0.800 | 0.800 |
| Excavation of rammed soil for wall (reinforced earth) | $m^3$ | Excavator (< 5% stones) | 0.030 | 0.030 |
| | $m^3$ | Backhoe loader | 0.030 | 0.030 |
| Standard/interchange bridges on main section | $m^2$ | Tower crane—small | 8.925 | 16.227 |
| Concrete for standard/interchanges bridges | $m^3$ | Concrete batching plant | 1.682 | 1.682 |
| | $m^3$ | Concrete pump—small | 0.800 | 0.800 |
| Major bridges on main section | $m^2$ | Tower crane—big | 4.463 | 8.114 |
| | $m^2$ | Drilling machine | 1.339 | 2.434 |
| Concrete for major bridges | $m^3$ | Concrete batching plant | 1.682 | 1.682 |
| | $m^3$ | Concrete pump—big | 0.400 | 0.400 |
| Excavation of tunnels | $m^3$ | Hydraulic hammer | 0.450 | 0.450 |
| | $m^3$ | Excavator | 0.045 | 0.011 |
| Concrete for tunnels | $m^3$ | Concrete pump—big | 0.400 | 0.400 |
| | $m^3$ | Concrete batching plant | 1.682 | 1.682 |
| | $m^3$ | Tower crane—big | 0.400 | 0.400 |
| **Road furniture** | | | | |
| Barriers | m | Concrete barrier slipform | 0.009 | 0.009 |
| Directional sign area | $m^2$ | Crane (mobile) | 4.460 | 4.460 |
| Streetlights | u | Crane (mobile) | 11.156 | 11.156 |
| Wayside amenities | $m^2$ | Tower crane—small | 4.463 | 0.000 |
| Concrete for all road furniture | $m^3$ | Concrete batching plant | 1.682 | 1.682 |

**TABLE B28 DEFAULT TRANSPORT DISTANCES**

| From | To | Value | Comment/material transported |
|---|---|---|---|
| Cut on site | Fill on site | Expressway: 2.5 km<br>National road: 2 km<br>Provincial road: 15 km<br>Rural road: 1 km | Used for earthworks and tunnel |
| Borrow Pit | Site | Expressway: 25 km<br>National road: 20 km<br>Provincial road: 15 km<br>Rural road: 10 km | Used for earthworks (fill from borrow pit) |
| Site | Disposal site | Expressway: 25 km<br>National road: 20 km<br>Provincial road: 15 km<br>Rural road: 10 km | Used for earthworks (evacuated cut) |
| Quarry | Batching plant | Expressway: 30 km<br>National road: 20 km<br>Provincial road: 10 km<br>Rural road: 7 km | Aggregates |
| Quarry | Site | Expressway: 30 km<br>National road: 20 km<br>Provincial road: 10 km<br>Rural road: 7 km | Aggregates |
| Quarry | Asphalt plant | Expressway: 30 km<br>National road: 20 km<br>Provincial road: 10 km<br>Rural road: 7 km | Aggregates |
| Asphalt plant | Site | Expressway: 20 km<br>National road: 10 km<br>Provincial road: 7 km<br>Rural road: 3 km | Bituminous bound materials |
| Batching plant | Site | Expressway: 20 km<br>National road: 10 km<br>Provincial road: 7 km<br>Rural road: 3 km | Cement bound materials |
| Cement plant | Batching plant | 250 km | Cement |
| Borrow Pit | Batching plant | Expressway: 25 km<br>National road: 20 km<br>Provincial road: 15 km<br>Rural road: 10 km | Sand for concrete |
| Refinery | Asphalt plant | 250 km | Bitumen |
| Cement plant | Site | 250 km | To be used for soil treatment<br>Cement<br>Lime |
| Refinery | Site | 250 km | To be used for surface treatment<br>Bitumen |
| Steel plant | Site | 250 km | Steel<br>No workshop assumed |
| Prefabrication Plant | Site | 150 km | Concrete prefabricated elements |
| Sawmill | Site | 150 km | Barriers in timber |
| Copper plant | Site | 500 km | Electric cables for lighting and other road facilities |

**TABLE B29 DEFAULT TRANSPORT FLEET CHARACTERISTICS**

| Distance | <25 km | 25–50 km | >50 km |
|---|---|---|---|
| Transport | 30%: Truck 6.1–10.9 t—diesel<br>70%: Truck 11–19 t—diesel | Truck 11–19 t—diesel | Truck 21.1—32.6 t—diesel |

## Land-Use Changes

ROADEO takes into account GHG emissions due to land-use changes and subsequent removal of above-ground biomass resulting from the implementation of road construction and rehabilitation projects.

The assessment of these emissions is made on the basis of the following data:

- Initial land cover type reflecting the typical land-use observed along the project alignment before its implementation (two types of vegetation can be selected by users from a pre-defined list);
- Area affected by land-use change (to be entered by users as a percentage of the project alignment for each initial land cover type);
- Above-ground biomass quantities (in dry metric tons/hectare) depending on land cover types found in Continental Asia (these values, shown in table B30, are based on data from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories); and
- Average density of $CO_2$ per dry metric ton of above-ground biomass (set to a commonly used value of 1.72 tons of $CO_2$ per dry metric ton).

The resulting values of GHG emissions, which may be significant—especially for greenfield projects in tropical and/or mountainous areas—are reported in the results tab of ROADEO and on the graph showing the distribution of project emissions according to the type of work component (in $tCO_2$).

**TABLE B30 ABOVE-GROUND BIOMASS DEPENDING ON LAND COVER TYPES IN CONTINENTAL ASIA**

| | Dry metric tons/ha | | |
|---|---|---|---|
| Land cover type | Low | Average | High |
| Tropical rainforest | 120 | 280 | 680 |
| Tropical moist deciduous forest | 10 | 180 | 560 |
| Tropical dry forest | 100 | 130 | 160 |
| Tropical shrubland | 60 | 60 | 60 |
| Tropical mountain system | 50 | 135 | 220 |
| Subtropical humid forest | 10 | 180 | 560 |
| Subtropical dry forest | 100 | 130 | 160 |
| Subtropical steppe | 60 | 60 | 60 |
| Subtropical mountain system | 50 | 135 | 220 |
| Temperate continental forest (<20 years) | 20 | 20 | 20 |
| Temperate continental forest (>20 years) | 20 | 120 | 320 |
| Temperate mountain system (<20 years) | 20 | 100 | 180 |
| Temperate mountain system (>20 years) | 20 | 130 | 600 |
| Boreal coniferous forest | 10 | 50 | 90 |
| Boreal tundra woodland (< 20 years) | 3 | 3.5 | 4 |
| Boreal tundra woodland (> 20 years) | 15 | 17.5 | 20 |
| Boreal mountain systems (< 20 years) | 12 | 13.5 | 15 |
| Boreal mountain systems (> 20 years) | 40 | 45 | 50 |

*Source:* 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

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