www.cepal.org/transporte

Issue No. 286 - Number 06 / 2010

ISSN 0256-9779

BULLETIN FAL

FACILITATION OF TRANSPORT AND TRADE IN LATIN AMERICA AND THE CARIBBEAN

Towards low-carbon transportation infrastructures

Introduction

It is estimated that transportation is responsible for 13% of all greenhouse gas emissions worldwide and 24% of the CO_2 associated with burning fossil fuels. The challenges posed by climate change have thus added to the urgency of developing low-carbon transportation.

There are three broad strategic goals for achieving this end. The first consists of avoiding demand by transportation. The second seeks to shift transportation towards cleaner modes, especially from private automobiles to walking, bicycles and public transit. The third calls for more efficient technologies.

Achieving these goals requires policies that address all emission sources associated with transportation. But the focus has traditionally been on controlling direct emissions, that is, those associated with the propulsion of vehicles (automobiles, buses, trains, aircraft and ships). Although such emissions account for a large part of transportation emissions, such a focus overlooks certain indirect emissions associated with activities that make vehicle propulsion possible.

To help fill this gap and further the progress being made toward low-carbon transportation systems in Latin America, this document provides a rationale for promoting the development of low-carbon transportation infrastructures. Taking a broad view of transportation infrastructure that encompasses not only its fixed, physical components but also what it is used for, for the purposes of this document a low-carbon transportation infrastructure is one that minimizes the carbon emissions associated with providing and operating that infrastructure.

With these goals in mind, this document is divided into five sections including this introduction. To contextualize the need to focus on the relevance of low-carbon transportation infrastructures, the following section provides background on the current demands for moving towards a low-carbon economy and on how to move towards low-carbon transportation. The next section provides a specific definition of a low-carbon transportation infrastructure, lists emission sources associated with it and summarizes a methodology for calculating its life-cycle emissions. The last section uses hypothetical examples to show how to calculate the life-cycle emissions of two infrastructure options for a specific transportation service: a road and a railway. The document ends with some broad recommendations.

This bulletin discusses the importance of low-carbon transportation infrastructures for the integrated development of the region. It is part of the work being done by the Unit on the project for environmental innovation in urban services and infrastructure: towards a carbon-free economy, funded by the Spanish Agency for International Development Cooperation (AECID). The author is Edmundo Claro, consultant, Infrastructure Services Unit.

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Introduction

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United Nations

ECLAC

ISU Infrastructure Services Unit

Natural Resources and Infrastructure Division, UNECLAC

I. Low-carbon transportation infrastructure

1. Definition

"The word 'infrastructure' originated in military parlance, referring to fixed facilities such as air bases. Today it is used to mean any important, widely shared, human-built resource" (Edwards, 2003). For example, NZIER (2004) notes that infrastructure is a set of assets that can only be changed by means of large, abrupt increments in capacity, with risks of non-utilization, high fixed costs and low marginal costs, with many users. According to the United Nations (2007), infrastructures are capital-intensive, long-lasting networks and structures that directly support economic production.

Also according to the United Nations (2007), infrastructures usually include public utilities (such as water supply and electricity), public works (streets and dams), transportation services (like railways and ports) and sanitation services (sewers and waste disposal, among others). Infrastructures thus support growth and development, with services that act as inputs for other productive processes (such as energy and transportation) or as products for final consumption (like drinking water and sanitation).

Because infrastructures profoundly condition user consumption patterns, choosing which ones are made and how they are designed will have a significant effect on energy consumption and the level of carbon emissions over the coming decades (Li and Colombier, 2009).[1] Developing low-carbon infrastructure will thus help pave the way for a low greenhouse gas emission economy (Scottish Government, 2010).

So, taking a broad view of a transportation infrastructure that includes not only its fixed physical components but also what it is used for, a low-carbon transportation infrastructure is one that minimizes the carbon emissions associated with providing and operating it. From this viewpoint, a low-carbon infrastructure is one whose carbon emissions are lower than the infrastructure alternatives available for providing a specific transportation service.

2. Emissions associated with a transportation infrastructure

The contribution of transportation to global warming is well known, but policies have tended to focus on controlling direct emissions (i.e., those associated with propulsion) from vehicles (automobiles, buses, trains, aircraft and ships) (Chester and Horvath, 2009; Jonsson, 2007). Although such emissions account for a large part of transportation emissions, such a focus overlooks certain indirect emissions associated with the activities that make vehicle propulsion possible. Noteworthy among these activities are those within the life cycle of vehicles, the fuels that propel vehicles, and the corresponding infrastructures (Chester and Horvath, 2009; Lenzen, 1999; Miliutenko, 2010).

For example, a study on passenger transportation in the United States shows that the "direct indirect emissions" per passenger-kilometre-travelled account for nearly 30% of total emissions for road transport, 60% for rail transport and 20% for air transport (Chester and Horvath, 2009). A study on road transportation in Sweden shows that indirect consumption accounts for 45% of total energy consumption, per the following breakdown: vehicle manufacture and maintenance, 14%; fuel production and distribution, 9%; infrastructure construction and servicing, 22% (Jonsson, 2007).

So, transportation infrastructure decisions that seek to advance towards a low-carbon system should be based on a broad approach to potential solutions that takes into account the total emissions (direct + indirect) associated with providing and operating each one. It is therefore necessary to estimate the direct emissions associated with vehicle propulsion and the indirect emissions associated with vehicle, fuel and infrastructure life cycle. Figure 1 shows this graphically.

All of these emissions are relevant for decision-making purposes, but for the sake of brevity and clarity the following section explains how to estimate life-cycle emissions just for infrastructures without going into those associated with the propulsion of the vehicles that use them, vehicle life cycle or fuel life cycle.

Figure 1
Total emissions of a transportation infrastructure

Emissions	Indirect			+	Direct	=	Total
	↑	↑	↑		↑		
Source	Infrastructure life cycle	Vehicle life cycle	Fuel life cycle		Vehicle propulsion		
Function	Provision	Operation					

Source: Prepared by the authors.

[1] For example, emphasizing the building of highways that encourage the use of private automobiles instead of the development of public transit systems will create an enormous future demand for fossil fuels for personal transportation modes, and carbon emissions will continue to grow (United Nations, 2007).

II. Methodology for calculating transportation infrastructure life-cycle emissions

According to Forum for the Future (2009), there are four phases in assessing an infrastructure's life-cycle carbon emissions. They are:

- defining the purpose of the analysis;
- developing the infrastructure life-cycle flow chart;
- gathering data; and
- calculating emissions.

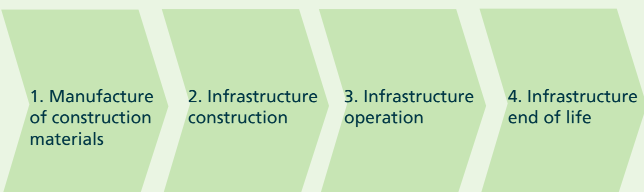
1. Defining the purpose of the analysis

In this phase, the reason for including carbon emissions in the decision-making process is defined and the product or service to be analysed is determined. It is also decided how the findings are to be interpreted and reported so that they will make sense and be useful. In other words, the findings should be organized on the basis of a functional unit describing the use of the service under study (SAIC, 2006).

2. Developing the infrastructure life-cycle flow chart

There are several stages in the life of an infrastructure. Each stage in turn involves inputs, processes and outputs. This phase of the analysis thus seeks to identify all the inputs, processes and outputs that contribute to the life cycle of the infrastructure under review. Studies show that an infrastructure's life-cycle emissions come, basically, from four stages and the transportation requirements between them: (a) manufacture of construction materials; (b) infrastructure construction; (c) infrastructure operation; and (d) infrastructure end of life (see figure 2).[2]

Figure 2
Infrastructure life cycle



Source: Prepared by the authors.

Below is a brief description of the infrastructure life-cycle stages and of the inputs, processes and outputs that generate carbon emissions.

[2] This definition of the stages of an infrastructure's life cycle and the explanation of each one come from a review of the following sources: AIA (2010); Collin and Fox (2010); Dai and Tang (2006); Jonsson (2007); Miliutenko (2010); Park et al. (2003); Treloar, Love and Crawford (2004); Torkington and Ulfves (2008).

Manufacture of construction materials

This stage includes obtaining the raw materials that will be used to manufacture the products for building the infrastructure, transporting them to the manufacturing site, manufacturing the construction materials and distributing them to the construction site. The manufacture of materials consists of transforming the raw materials into products that can be used to build infrastructure.

Infrastructure construction

During the infrastructure construction stage, the infrastructure components are assembled from the products manufactured in the preceding stage. This includes activities such as preparing the land; moving materials and machinery; building roadways; installing offices, signage, piping, lighting and other components; and moving workers to and from the construction site.

Infrastructure operation

Running and maintaining an infrastructure are the activities associated with the operation stage. The activities involved in operating an infrastructure, such as lighting, cleaning and accident control, make it possible to use the infrastructure. Maintenance involves replacing corroded components, painting structures, and improving the pavement, among other activities.

Infrastructure end of life

This stage of the infrastructure life cycle usually begins with demolition and continues with management of the resulting waste materials. This stage thus includes emissions generated while demolishing the infrastructure, transporting the refuse to a dump or a recycling plant and disposing of or recycling the refuse.

3. Gathering data

Two kinds of data are needed to calculate the carbon emissions of an infrastructure: those related to activity, and emission factors. Data on activity refer to all material inputs and outputs, energy used and the transportation involved in the life cycle defined for the infrastructure. Emission factors provide the link that converts these amounts into the resulting carbon emissions: the amount of carbon emitted per "unit" of data for an activity (example: CO_2/kg or CO_2/kWh) (BSI, 2008).

Both kinds of data can come from primary or secondary sources. Primary data refer to direct measurements of the supply chain for the infrastructure in question. Secondary data refer to indirect measurements that are not specific to the infrastructure in question but rather reflect an average or general measurement for similar processes or materials. While it is generally recommended to use

primary data as much as possible because they provide a better understanding of actual emissions, secondary data must be used when primary data are unavailable or might be unreliable (BSI, 2008).

4. Calculating emissions

The equation for estimating the carbon emissions of the infrastructure in question is the sum of all the data on the activity (all material inputs and outputs, all energy used, all transport and all physical changes in the landscape) associated with all of the infrastructure life-cycle activities, multiplied by their respective emission factors. In other words, the calculation per se merely consists of multiplying the data for each activity by the appropriate emission factors according to the following diagram:

CO_2 emissions for an activity	=	Data on the activity (mass, volume, energy, length, etc.)	x	Emission factor (CO_2/unit)

Source: Prepared by the authors.

III. Example [3]

To illustrate this methodology, set out below is a summary of the estimate and a comparison of the emissions associated with the development of passenger transportation infrastructure alternatives for linking two population centres that are 9.68 kilometres apart.[4] The first alternative is a road that would primarily be for private vehicles. The second is a passenger railway. Table 1 summarizes the main features of both infrastructures.

Table 1
Infrastructure features

Feature	Infrastructure	
	Road	Railway
Mode	Average diesel-powered sedan	ICE 2 electric high-speed train
Length	9.68 km	9.68 km
Width	10 m	6 m
Frequency	2 000 trips/day (1 000 outbound and 1 000 return)	10 trips/day (5 outbound and 5 return)
Load	1 passenger/trip	150 passengers/trip
Performance	36 500 000 passengers	27 375 000 passengers
Fuel	Diesel	Electricity
Consumption	0.09 litres/km	20 kwh/km
Useful life	50 years	50 Years

Source: Prepared by the authors.

1. Defining the purpose of the analysis

The purpose of the analysis is to evaluate and compare life-cycle stage carbon emissions and their emission sources for the road and railway depicted in the table above. Because the length of both infrastructures is the same (9.68 km), the functional unit chosen for evaluating the project is passenger transported.

2. Developing the infrastructure life-cycle flow chart

Like all infrastructure, the road and the highway have four life-cycle stages: (a) manufacture of construction materials; (b) construction; (c) operation; and (d) end of life. Table 2 shows the principal inputs and processes associated with these stages for both infrastructures.

3. Gathering data

Because the analysis is a hypothetical one, the data on the activity and emission factors come from secondary sources for both infrastructures. Tables 3 and 4 summarize the data gathered.

[3] This example is from the summary of a hypothetical exercise developed for this study. Details on the exercise are available in a document soon to be published by ECLAC.
[4] This distance is from Mpele et al. (2010), who analyze the energy requirements for a road link between northern Cameroon and southeastern Chad.

Table 2

Infrastructure inputs and processes

Stage	Infrastructure	
	Road	Railway
Manufacture of construction materials	Aggregates Concrete Asphalt	Aggregates Concrete Steel Wood
Construction	Preparing the land Building the structure Paving	Preparing the land Building the embankment Laying sleepers and rails
Operation	Pavement maintenance	General infrastructure maintenance
End of life	Demolition Disposal of refuse in a landfill	Demolition Disposal of refuse in a landfill

Source: Prepared by the authors.

Table 3

Data for the road

Stage	Emission source	Data on the activity	Emission factor (kg CO_2)
Manufacture of construction materials	Manufacturing asphalt	92 575 tons[a]	21.48/tons[b]
	Manufacturing concrete	111 tons[a]	4.13/tons[b]
	Manufacturing aggregates	503 768 tons[a]	2.85/tons[b]
	Transporting asphalt to construction site	92 575 tons[a]	1.05/Truck-km (empty on return)[c]
	Transporting concrete to the construction site	111 tons[a]	1.05/Truck-km (empty on return)[c]
	Transporting aggregates to the construction site	503 768 tons[a]	1.05/Truck-km (empty on return)[c]
Construction	Preparing the land	1 171 671 m^3 [a]	30/m^3 [d]
	Building the structure	314 901 m^3 [a]	30/m^3 [d]
	Paving	40 250 m^3 [a]	300/m^3 [d]
Operation	Pavement maintenance	18 515 tons per maintenance cycle[e]	136.57/tons[f]
End of life	Demolition: tearing up the road	87 120 m^2 [a]	7.78/m^2 [g]
	Demolition: moving materials	596 454 tons[a]	2.85/tons[g]
	Transporting refuse to landfill	596 454 tons[a]	1.05/Truck-km (empty on return)[c]
	Disposing of asphalt in landfill	92 575 tons[a]	4.54/tons[h]
	Disposing of concrete in landfill	111 tons[a]	0/tons[h]
	Disposing of aggregates in landfill	503 768 tons[a]	0/tons[h]

Source: Prepared by the authors.

[a] Mpele et al. (2010).
[b] Watkins (2009).
[c] Stripple (2001).
[d] Forum for the Future (2009).
[e] Athena Institute (2006).
[f] Compiled by author based on Watkins (2009), Stripple (2001) and Forum for the Future (2009).
[g] Nianxiong, Jing and Rong (2008).
[h] Lewis (2008).

4. Calculating emissions [5]

The estimated emissions for the road life cycle show that the construction stage is clearly the one that generates the most emissions (73.67% of the total), followed by operation (13.15% of total emissions), manufacture of materials (7%) and end of life (6.18%). Assessing emissions by source shows that preparing the land generates the most emissions, at 45.70% of the total.

The estimated emissions for the railway life cycle show that here, too, the construction stage accounts for the most emissions, with 59.65% of the total, followed by operation (22.69% of total emissions), manufacture of materials (15.24%) and end of life (2.42%). Assessing emissions by source shows that preparing the land generates the most emissions, at 55.20% of the total. Set out in Table 5 is a summary of this information.

[5] These estimates could contain distortions associated with gathering data on activity and emission factors.

Table 4
Data for the railway

Stage	Emission source	Data on the activity	Emission factor (kg CO_2)
Manufacture of construction materials	Manufacturing steel	3 113 tons[a]	1 800 tons[a]
	Manufacturing concrete	12 040 tons[a]	4.13/tons[b]
	Manufacturing wood	4 988 tons[a]	150/tons[c]
	Manufacturing aggregates	420 tons[d]	2.85/tons[b]
	Transporting steel to the construction site	3 113 tons[a]	1.05/Truck-km (empty on return)[c]
	Transporting concrete to the construction site	12 040 tons[a]	1.05/Truck-km (empty on return)[c]
	Transporting wood to the construction site	4 988 tons[a]	1.05/Truck-km (empty on return)[c]
	Transporting aggregates to the construction site	420 tons[d]	1.05/Truck-km (empty on return)[c]
Construction	Preparing the land	781 114 m3 [f]	30 m3 [a]
	Building the embankment	25 168/m3 [d]	30 m3 [a]
	Laying sleepers and rails	37 765 m3 [a]	30 m3 [a]
Operation	Maintenance	-	19 900/km-year[g]
End of life	Demolition: railway demolition	58 080 m2 [f]	7.78/m2 [h]
	Demolition: moving materials	20 561 ton[a,d]	2.85/tons[h]
	Transporting refuse to landfill	20 561 ton[a,d]	1.05/Truck-km (empty on return)[c]
	Disposing of steel in landfill	3 113 tons[a]	4.54/ton[i]
	Disposing of concrete in landfill	12 040 tons[a]	0/tons[j]
	Disposing of wood in landfill	4 988 tons[a]	90/tons[i]
	Disposing of aggregates in landfill	420 tons[d]	0/tons[j]

Source: Prepared by the authors.

[a] Forum for the Future (2009).
[b] Watkins (2009).
[c] IWEPS (2001).
[d] UIC (2009).
[e] Stripple (2001).
[f] Mpele et al. (2010).
[g] Simonsen (2010).
[h] Nianxiong, Jing and Rong (2008).
[i] EPA (2006).
[j] Lewis (2008).

Table 5
Infrastructure life-cycle emissions

Stage	Infrastructure			
	Road		Railway	
	Total emissions (kg CO_2)	Relative emissions (Percentages)	Total emissions (kg CO_2)	Relative emissions (Percentages)
Manufacture of materials	5 381 823	7.00	6 469 524	15.24
Construction	56 672 167	73.67	25 321 412	59.65
Operation	10 114 080	13.15	9 631 600	22.69
End of life	4 754 722	6.18	1 026 865	2.42
Total	76 922 792	100.00	42 449 402	100.00

Source: Prepared by the authors.

5. Including emissions associated with propulsion of vehicles and vehicle and fuel life cycle

Although the exercise above affords an understanding of and makes it possible to compare emissions associated with developing the infrastructures in question, it did not take into account the emissions associated with their use. The exercise did not consider direct emissions associated with vehicle propulsion or indirect vehicle and fuel life cycle emissions. Table 6 shows the findings of a brief exercise to calculate these emissions for each infrastructure alternative.[6]

[6] The findings set out here come from a hypothetical exercise developed for this study. Details on the exercise may be found in document XXX.

Table 6
Emissions associated with vehicle propulsion and vehicle and fuel life cycle (kg CO_2)

Source	Infrastructure	
	Road	Railway
Vehicle propulsion	73 137 240	0
Vehicle life cycle	32 378 955	5 283 090
Fuel life cycle	6 359 760	745 505

Source: Prepared by the authors.

6. Comparison

These analyses provide grounds for arguing that of the two alternatives examined (road and railway), developing the railway is clearly the low-carbon infrastructure alternative. This is based on total emissions for each alternative and also on their emissions per passenger transported. Table 7 provides a summary of this information.

Table 7
Emissions for the infrastructures reviewed (kg CO_2)

Source	Infrastructure	
	Road	Railway
Infrastructure life cycle	76 922 792	42 449 402
Vehicle propulsion	73 137 240	0
Vehicle life cycle	32 378 955	5 283 090
Fuel life cycle	6 359 760	745 505
Total emissions	188 798 747	48 477 997
Emissions per passenger transported	5.17	1.77

Source: Prepared by the authors.

IV. Recommendations

While studies agree that infrastructure decisions have a limited impact on greenhouse gas emissions in the short term, they show that such decisions can have a substantial effect over the long run (Grazi and van den Bergh, 2008). According to Environment California Research & Policy Center (2008), transportation infrastructure decisions made over the next few years will affect emissions for decades. These decisions should therefore be weighed in terms of their impacts on global warming, giving preference to those with a lower level of emissions.

The challenge that decision-makers face is thus to promote those infrastructure solutions that generate the lowest carbon emissions for providing a specific transportation service. For this reason, when assessing decisions on transportation between cities and between rural and urban areas, several options for transporting passengers and cargo should be considered instead of looking at just one mode in particular.

Similarly, when evaluating solutions for urban automobile transportation problems, options such as how to improve alternative transportation modes should be considered in addition to expanding existing roadways or building new ones (Litman, 2008). In this regard, there is a consensus in the specialized literature that advancing towards a low-carbon transportation system requires increasing and improving the public transit and non-motorized transportation infrastructure.

Assuming that a decision has been made concerning the mode and capacity of the transportation system to be developed, and assuming that implementing that decision requires building a new infrastructure, all of the life-cycle emissions of the infrastructure options being considered must be evaluated and the one with the lowest emissions chosen in order to advance towards a low-carbon infrastructure. An exercise of this kind makes it possible to compare the emissions associated with issues like these: Should roads be built to follow the natural topography, or should cuts and tunnels be used? What material should be used to build a bridge: concrete or steel? (Horvath, 2009).