A LIFE CYCLE ANALYSIS OF CARBON-DIOXIDE FROM TRANSPORT INFRASTRUCTURE USING INPUT-OUTPUT SCHEME : A CASE STUDY OF TOHOKU EXPRESSWAY IN JAPAN *

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1. Introduction

Life Cycle Assessment (LCA) has been widely applied for the study of environmental impact for industrial products and processes. However, there have been no studies related to LCA of transport infrastructure. Though a transportation system provides us the mobility of people and goods, it is also cited as a major source of contaminants to the environment. We cannot deny that the deterioration of the environment can cause feedback effect to human heath, moreover, in long run, the efficient functioning of the economy. Ergo, to achieve the sustainable transportation system it is necessary to appraise the impact of the project before the approval of the project. Especially, in case of carbon dioxide, because the emission can be accumulated in long run, they must be contemplated all over the project's life cycle. The concept of life cycle emission from the expressway can be illustrated in Figure 1.

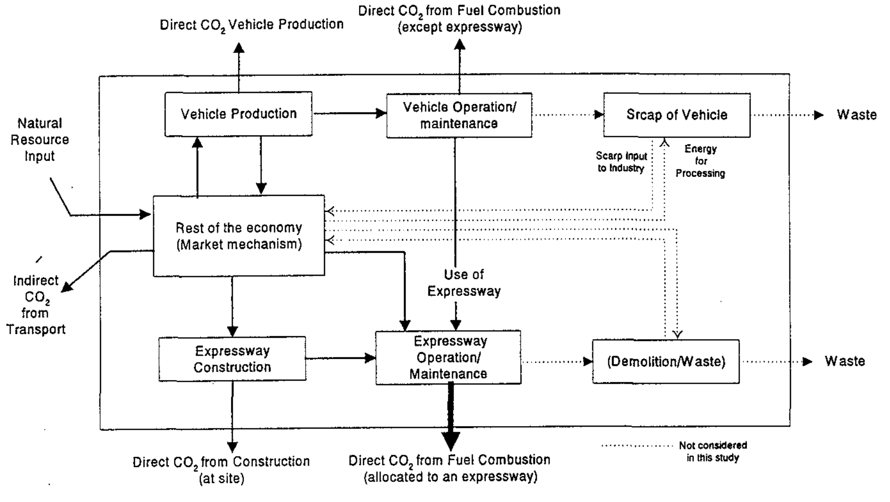

Figure 1: Concept of Life Cycle Analysis of CO2 Emission from Expressway

There are two important aspects to consider in LCA. The first aspect is to account the emission not only in the operation phase, but also throughout its life cycle. In case of expressway, the emission from the construction and maintenance of an expressway has to be considered. The demolition of the project after its lifetime may consume enormous energy and may be not economical. In this study, it was simply assumed that the project will not be demolished after its lifetime. The second important aspect needed to be considered in LCA is the production chain of the product or process. In case of expressway construction, direct energy need and direct emission at site may be considered tiny. However, the project requires a lot of raw material and products. Even the material itself does not emit any emission, but it is also needed a lot of energy to extract it from the nature, to process the raw material, to transport to the retailers and final users. In this aspect, it is also needed to include the emission embedded in raw material from the project construction. In the operation phase, the indirect emission for extracting and transporting of the fuel has to be considered. Regarding the expressway, the emission from car production is

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estimated and allocated into the expressway by the proportion of its performance on the expressway to its lifetime performance in term of vehicle-km. However, a comparison between passenger transport mode should be based on passenger-km unit while freight transport has to be compared based on ton-km basis. The research framework is shown in figure 2.

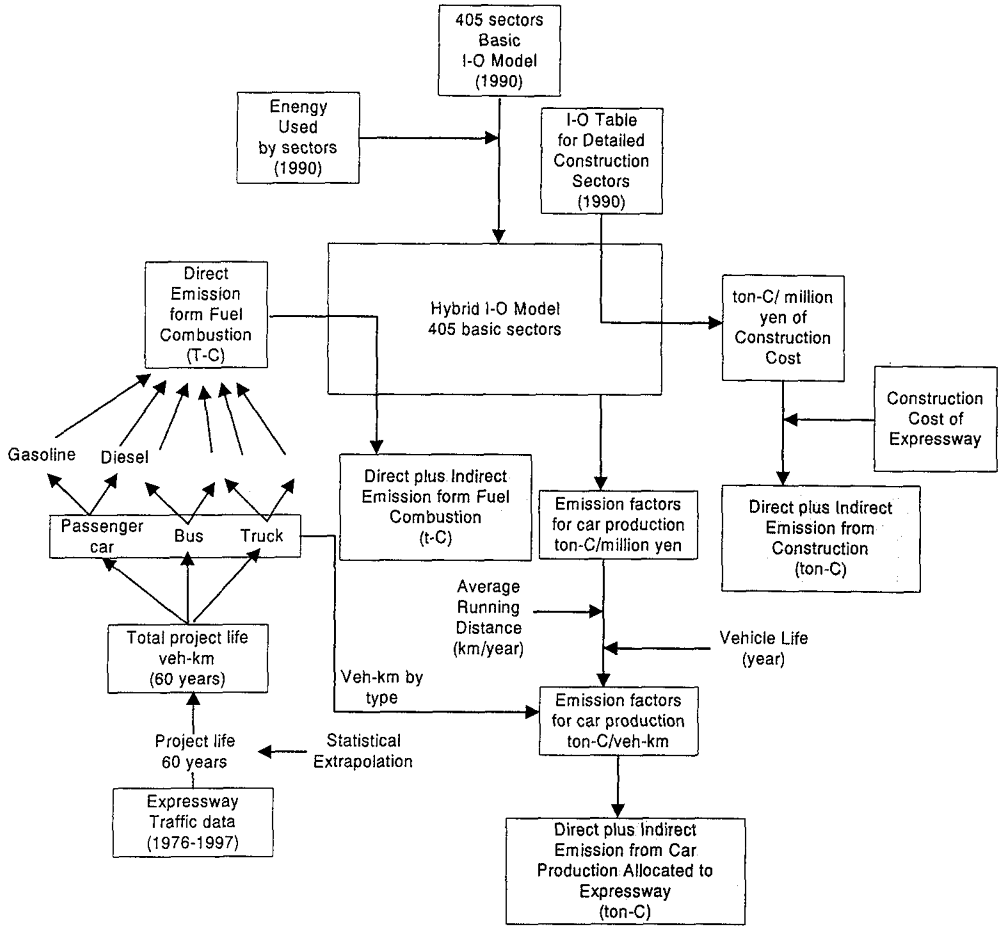

Figure 2: Research Framework

2. Methodology

In this study, we applied an Input-Output (I-O) model because the model is particularly suitable for the analysis of life cycle emission from transport infrastructure. There are many reasons to support the merit of using in-put-output model. One of the problems in LCA study is the availability of the database. Recently, input-output data is available in most countries. Another of the reason is that the model can capture the interaction effects (both direct and indirect) of the complex production chain within the framework of the economy. Following Leotief [1], the basic I-O model can be described as following.

Any sector's output is equal to its intermediate consumption required by other industries plus its net final consumption. The balance equation of any industry can be described as

$$X_i = \sum_j T_{ij} + Y_i \tag{1}$$

Where X_i is industrial output, T_{ij} is intermediate input from sector i required by sector j, and Y_i is the net final demand for sector i.

Input-output model makes an assumption that the intermediate input required is proportional to the output of that industry. This statement can be expressed by

$$T_{ij} = a_{ij} X_j \tag{2}$$

Where a_{ij} is a constant called technical coefficient. Combining equation (1) and (2) gives

$$X_i = \sum_j a_{ij} X_j + Y_i \quad (3)$$

For the economy of n industrial sectors, we can write a set of equations in the matrix form of

$$X = AX + Y \quad (4)$$

Where	X	=	vector of industry output	(nx1)
	A	=	technical coefficient matrix	(nxn)
	Y	=	vector of net final demand	(nx1)

Solving for a set of output (X) required to satisfy an exogenous given set of final demand (Y) gives

$$X = (I - A)^{-1} Y \quad (5)$$

From equation 5, we can estimate the output needed to satisfy any set of final demand. Although the model is derived in physical term, input-output relationship is usually expressed in monetary term for the sake of convenience. To calculate the emission, in this study, we applied the hybrid model, that the money terms in primary energy sector rows were replaced by the associated emission in physical term. In this study, it was assumed that all technology included construction technology, vehicle production technology, fuel consumption technology, are of 1990.

3. Data sources

The basic data using for the analysis are summarized as following.

(1) Study Period: In this study, the lifetime of the expressway was assumed to be 60 years since the project was opened for service
(2) Basic I-O data (1990)
  a) I-O Table 405 sectors [2)]
  b) Construction I-O table [3)] (207, sectors input coefficient for road construction works)
(3) Tohoku Expressway Construction Cost by Categories: Data from Japan Highway Public Corporation (JH).
(4) Tohoku Expressway Traffic data 1976-1997: Data from Japan Highway Public Corporation (JH).
(5) Tohoku Expressway Maintenance: Data from Japan Highway Public Corporation (JH).
(6) Cost deflators for road construction works: Japan Statistical Yearbook [5)]
(7) Number of vehicle classified by type of fuel: National Transportation Statistics Handbook [4)]

4. Result of the Analysis

The hybrid I-O model has been developed from the basic 405-sector I-O model. The result after combining with construction I-O data can be summarized in Table 1.

Table 1 Various emission factors derived from the model

Item	Direct	Direct + Indirect	Unit
Expressway Construction			
Bridge	0.207	1.200	ton-C/million yen
Pavement	0.267	0.877	ton-C/million yen
Tunnel & Earthwork	0.257	0.901	ton-C/million yen
Other works	0.204	0.915	ton-C/million yen
Expressway Maintenance	0.195	0.922	ton-C/million yen
Car Production			
Passenger Car	0.023	1.042	ton-C/vehicle
Truck	0.029	1.552	ton-C/vehicle
Bus	0.077	4.179	ton-C/vehicle
Fuel		1.047	kg-C / kg-C
Gasoline	0.643300		kg-C / liter
Diesel	0.721200		kg-C / liter

Source: Author's calculation

The amount of life cycle emission for Tohoku Expressway can be estimated by applying the calculated emission factors in Table 1 with the project data. The result is shown in Table 2.

Table 2 Summary of carbon emission from Tohoku Expressway (ton-C)

Life Cycle Stage	Item	Direct	Direct+Indirect	Percentage
Production of car	Passenger Car	53,463	2,371,557	
	Bus	1,636	88,968	
	Truck	21,175	1,151,263	
		76,275	3,611,789	5.07%
Expressway construction	Earthwork	2,203	496,459	
	Pavement	2,153	195,945	
	Tunnel	810	182,396	
	Bridge	1,344	466,056	
	Other works	5,556	849,526	
		12,066	2,190,382	3.07%
Expressway maintenance		52,379	247,299	0.35%
Car operation	Passenger Car	15,058,821	15,770,312	
	Bus	1,589,796	1,664,910	
	Truck	45,608,874	47,763,776	
		62,257,491	65,198,998	91.51%
Total		64,576,527	71,248,468	100.00%

The unit emission based on functional unit of passenger and freight transportation on expressway was calculated and shown in Table 3.

Table 3 Amount of carbon emission per functional unit

Type of vehicle	Amount	Unit
Passenger Car	43.50	ton-C / million passenger-km
Bus	6.80	ton-C / million passenger-km
Truck	43.55	ton-C / million ton-km

5. Conclusion

From the result of the study, it was found that, incase of expressway, most of emission comes from the fuel combustion in the operating stage. The rest of emission most comes from the production of car, project construction, and project maintenance respectively. The result is very useful to make a clear picture for the life cycle carbon emission from expressway. Possible solutions may be to change the production process and raw material for car production and also for expressway However, from this study, it is clear that to improve vehicle fuel consumption efficiency might be the most effective way to reduce the emission from the expressway. It is not surprising that the emission per passenger-km of bus is lower than that of passenger car due to the nature of mass transportation. This also revealed the high potential of reducing carbon emission from transport by promoting mass transportation.

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