Journal of Environmental Science and Engineering B 1 (2012) 1-18
Formerly part of Journal of Environmental Science and Engineering, ISSN 1934-8932

Long-Term Environmental Accounting on Civil Infrastructures in Developing Countries

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Received: June 20, 2011 / Accepted: July 14, 2011 / Published: January 20, 2012.

Abstract: This paper proposes the environmental burden and benefit assessment method, which contributes to the evaluation of public works, by considering a quantitative environmental impact. The method developed is applied for the Bangkok subway construction project, so that the environmental impact following the Bangkok subway construction work is evaluated on the basis of environmental accounting. As a result, it was possible to quantify the burden and benefits to the environment in the life cycle of the Bangkok subway. In addition by converting the burden and benefits of the Bangkok subway construction project into monetary terms and introducing the Economic Internal Rate of Return (EIRR), it was possible to evaluate the subway construction project from an economic point of view.

Key words: Cost benefit analysis, emission factor, environmental cost, infrastructure.

1. Introduction

Recently, environmental concern to control greenhouse gases like CO_2, mentioned in the Kyoto Protocol, is accepted widely all over the world. As for developing countries, however, due to the very fast economic development they are not able to follow the environmental regulations, resulting in a serious deterioration, namely atmospheric pollution.

The subway in the Kingdom of Thailand and the Bangkok city region (the area including Bangkok and surrounding 5 prefectures, namely Samut Prakan, Patontani, Samutsakan, Nakonpatom and Nontaburi), that is a main concern of this study, has been launched by the Thailand Mass Rapid Transit Authority (MRTA) in 1996. It is hereafter referred to as "Bangkok subway construction project." Specifically "Blue Line", which is the work on a segment of the track with a Yen loan from the Japan Bank for International Cooperation (JBIC), was started to construct in 1996 and the operation commenced in 2004. The Bangkok subway construction project was planned against both of chronic traffic jams in the Bangkok city area and the lack of mass public transport facilities.

As aforementioned, infrastructure projects such as Bangkok subway construction project are often carried out with financial assistance from such public service organizations as national-authorities, local-authorities and international organizations as a form of Official Development Assistance (ODA). Thus, the resultant benefits of the project shall be returned to the financer, namely taxpayers. As these are carried out as a public service, it is not sufficient to consider only the expenditure and profits resulting directly from the project itself, but is necessary to consider the impact on the surrounding environment and society accompanied with public infrastructure works.

One of the impacts from the works is the emission of environmental pollutants like CO_2 on environment or society. A large quantity of environmental pollutants emissions increase the burden/load on future society. Thus, the impact of pollutants like CO_2

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on the environment has to be quantitatively considered when planning infrastructural projects.

This study proposes an environmental burden and benefit assessment method, which contributes to the evaluation of public works, by considering the quantitative environmental impact. As for an application with proposed method the environmental impact following the Bangkok subway construction work is evaluated.

2. Method for Assessment of Environmental Burden and Benefit

Recently, considerable efforts are being made for control the emission of greenhouse gases like CO_2 and such atmospheric pollutants as SO_x and NO_x in various fields. It is then important to quantify the environmental impact not only for public infrastructural projects but for all types of projects. The Life Cycle Assessment (LCA) method is an internationally standardized method for environmental impact assessments, providing the overall assessment of the impact of a product considered environmental factors in all stages from its production, use and to disposal [1]. The assessment of the overall environmental burden by using the LCA has been applied actively in such cases as industrial products like PET bottles as to reduce the burden on the environment in its life cycle. The LCA gives a procedural concept, and the specific procedure of assessment is determined by the individual characteristics. In general LCA mainly focuses on industrial products; however, public infrastructure differs from the industrial products as it is produced only once.

Fig. 1 shows the concept of the method for the assessment of environmental burden and benefit on public infrastructures. In the method determination of both the period and the area to be assessed are crucial. In the assessment of the burden and benefit method, the project life of the infrastructure was considered as the period to be assessed. For the region affecting the environment, there need to be considered two aspects: the region directly influenced by the infrastructure project, being referred to as “direct environmental impact”, and the region of direct/indirect scale including entire industry, namely “direct/indirect environmental impact”. In this study the positive impact (benefit to the environment) with the project was also considered in addition to the negative impact. It is expected that the operation of the civil infrastructure project may cause positive change in social systems, e.g., the mass transportation “subway” suggests an additional option for habitants to move instead of automobiles. This leads to decrease the number of people using automobile, which results in increase of vehicle speed. Correspondingly the vehicles are expected to move more smoothly with less fuel consumption, so that the quantity of emissions could be reduced. In this study, this type of reduction of impact due to the civil construction project is defined as an environmental benefit.

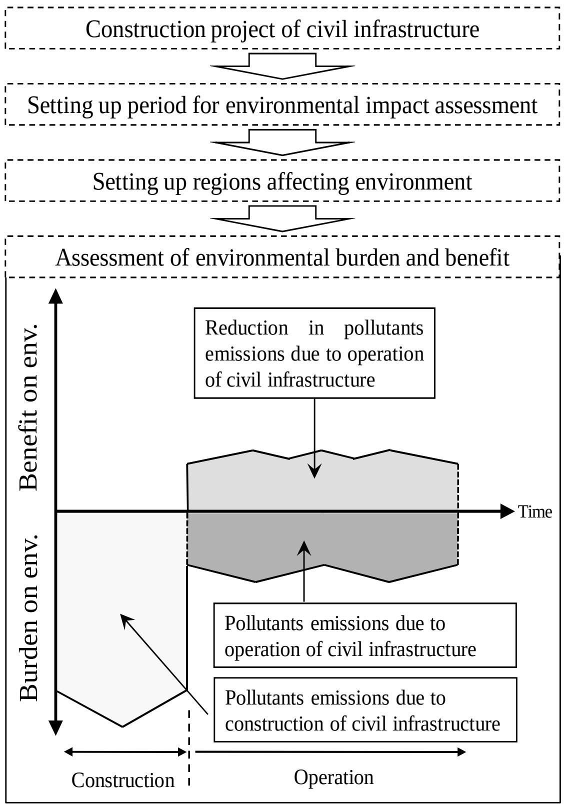


Fig. 1 Simple overview of proposed environmental burden and benefit assessment on civil infrastructure.

2.1 Emission Coefficients and Affecting Region of Environment

In order to consider the impact on the environment, it is essential to quantify the emissions of substances due to civil infrastructure project. The emissions are quantified by emission coefficients corresponding to the each element in used materials and energy.

The emission coefficient can relate the quantity of elements (like materials, construction machinery, fuel and electric power) used and environmental pollutants. Eq. (1) can be used for each of the elements.

$$EM_i = E_i \times W_i \quad (1)$$

where, EM_i: quantity of environment-affecting substance emitted by an element i, E_i: emission coefficient of element i and W_i: the quantity of element i used.

The emission coefficients of various elements and the estimating method are determined individually in organizations. The methods estimating emission coefficients can be classified into the build-up method and industry-related analysis. In this study, the latter, industry-related analysis is employed.

Specifically, for estimating the emission coefficient for each element which constitutes the civil infrastructure, an industry-related table for the year 1995 was referred to. In the industry-related analysis method, the emission impact of an element can be divided into several stages: production, distribution; and final domestic or overseas consumption branches and capital formation. Then the emission coefficient of element i can be expressed as in Eq. (2).

$$E_i = e_{ip} + e_{id} + e_{ic} + \cdots \quad (2)$$

where, E_i: emission coefficient of element i obtained from all the stages, e_{ip}: emission coefficient of element i in the production, e_{id}: emission coefficient of element i in the distribution, and e_{ic}: emission coefficient of element i in the consumption.

Table 1 shows the emission coefficients of CO_2, SO_2 and NO_2 obtained by the industry-related analysis and estimated by referring to the literature. In the case of electric power, which is one of the constituting elements of civil infrastructure, although CO_2, SO_2 and NO_2 are generated in the production (electricity generation) stage, it does not put any burden on the distribution/consumption stage; however, electric power has the potential to induce various demands. Correspondingly, in the case of the emission coefficient of electric power (E_e), in addition to the

Table 1 Emission coefficients of CO_2, SO_2 and NO_2 for representative elements composing civil infrastructure.

		Unit	Production e_{ip}	Distribution e_{id}	Consumption e_{ic}	Total E_i
	Materials					
	Concrete	t-CO_2/t	0.198	0.007	0	0.205
CO_2	Steel bar	t-CO_2/t	0.927	0.014	0	0.941
	Fuels					
	Gasoline	kg-CO_2/L	0.492	0.070	2.321	2.883
	Light oil	kg-CO_2/L	0.308	0.039	2.657	3.004
	Materials					
	Concrete	kg-SO_2/t	0.089	0.010	0	0.099
SO_2	Steel bar	kg-SO_2/t	1.466	0.030	0	1.496
	Fuels					
	Gasoline	g-SO_2/L	2.532	0.175	0.035	2.742
	Light oil	g-SO_2/L	1.694	0.077	2.618	4.389
	Materials					
	Concrete	kg-NO_2/t	0.433	0.028	0	0.461
NO_2	Steel bar	kg-NO_2/t	3.294	0.082	0	3.376
	Fuels					
	Gasoline	g-NO_2/L	3.059	0.457	2.566	6.082
	Light oil	g-NO_2/L	2.080	0.231	17.60	19.91

environmental pollutants emission when generation (e_{ep}), the emission of environmental pollutants resulting from induction of public demand (demand-induced emission: e_{em}) and environment-affecting emission induced by the capital formation of civil infrastructure (capital formation-inducing emission: e_{ef}) have to be considered. Table 2 shows details of the emission coefficient of electric power estimated from the industry-related analysis in case of CO_2, SO_2 and NO_2.

Eq. (2) shows the environment-affected region in the method of environmental burden and benefit assessment. Where, E_i on the left hand side, expresses the emission coefficient of each element i , being referred to as direct/indirect environment affected region, while a particular right hand side e_i after considering the condition of usage of various elements i, expresses the direct environment-affecting region directly affected by the civil infrastructure namely direct environment affected region.

The estimated emission coefficient of element i as shown in Table 1 and Table 2 shall be a variable that depends on technological innovations or economic changes; however, as the emission coefficient can be estimated from the past information, it is difficult to predict the future trend of the emission coefficient. The estimated emission coefficient is thus assumed to be constant and independent of time.

2.2 Assessment Period on the Environmental Impact

For setting the period of evaluation in the assessment of environmental burden and benefit, the system boundary (an index showing environmental conditions) is used. As can be seen in Fig. 2, the system boundary means how much details the study is dealt with for each process during the life cycle. In the previous research [2], the impact on the environment of the disposal stage of the civil infrastructure was extremely small as compared to the others. Thus, in the assessment method, the impact on the environment in the disposal stage of the civil infrastructure is not considered. Furthermore, in the environmental burden and benefit assessment method, the system boundary is set into two stages: construction and operation stages, enabling the separate estimation of the quantity of environment-affecting emitted substances in the construction and operation stages.

2.3 Introduction of Environmental Cost

In the environmental burden and benefit assessment method after the setup of aforementioned conditions as the environment-affecting region and the period, it is possible to predict the quantity of emissions of environmental pollutants following the civil infrastructure project. The quantity of emissions of environmental pollutants predicted by the present assessment method is converted into money (environmental cost), by using the basic unit quantity (described later) of emissions. Thus, this assessment enables to evaluate the impact of the civil infrastructure project on the environment even on the basis of environmental cost.

In recent years, as represented by CO_2 emissions trading, the concept of paying compensation against the emission of environmental pollutants is becoming more general. This compensation is known as damage cost. Furthermore, the compensation against the unit quantity of emissions of environmental pollutants is the basic unit of damage cost. Currently a lot of research is in progress on the basic unit for damage cost of environmental pollutants. Moreover, in various companies, with reference to various researches and

Table 2 Emission coefficients of CO_2, SO_2 and NO_2 for electric power.

	Unit	Generation e_{ep}	Demand-inducing e_{em}	Capital formation-inducing e_{ef}	Total E_e
CO_2	kg-CO_2/kWh	0.424	0.106	0.034	0.564
SO_2	g-SO_2/kWh	0.254	0.159	0.048	0.461
NO_2	g-NO_2/kWh	0.265	0.256	0.094	0.615

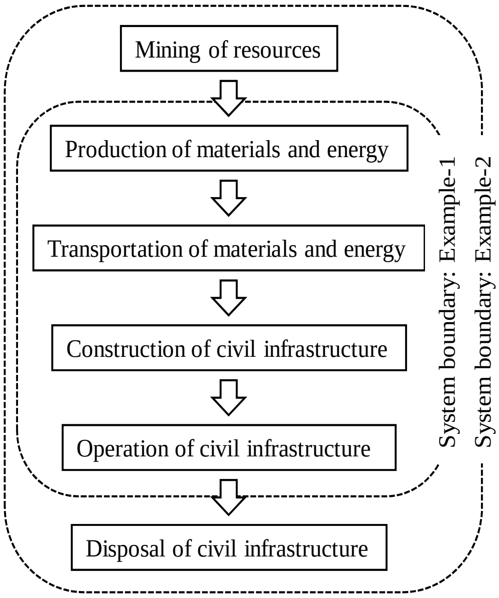


Fig. 2 Concept of system boundaries in life-cycle of civil infrastructure.

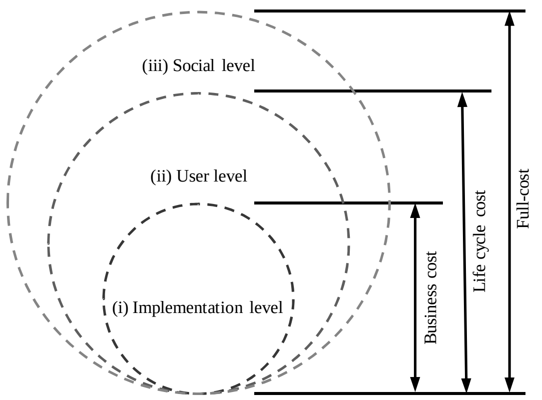
the market value in emission rights trading, basic units for damage cost of environmental pollutants are being established in the individual industries for clearly defining their own responsibilities. Table 3 is a compilation of the basic units for damage cost of the environmental pollutants. From this, there is a large variation in the basic unit of damage cost, namely no uniform basic unit. Thus, in this study, the conversion into monetary terms (introduction of environmental cost) of the impact of the civil infrastructure project on the environment is done by setting up a range for the basic unit for damage cost (see Table 3) by referring to the basic unit of the damage cost of environmental pollutants from the past research or from values calculated by the companies.

Furthermore, the cost required for a series of projects can be classified into: (1) cost and benefit at the basic level of implementation; (2) cost and benefit at the user level; and (3) cost and benefit at the level of the society (see Fig. 3a). So far, companies proposed and accomplished business by considering mainly: (1) and (2). This may be because: (1) and (2) greatly influence the income and expenditure of the main constituent of business application. On the other hand, at present where environmental concern is increasing, the main constituent of business application cannot stop at: (1) and (2), but a business proposal and accomplishment with consideration of (3) is also desired. Moreover, for considering (3), it is important to establish a method of assessing business which takes into account the effect of the business on the environment.

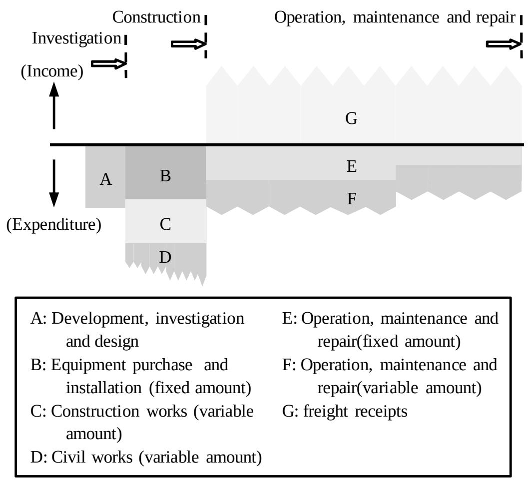
One of the ways to consider the above-mentioned (3) is to focus on Internal Rate of Return (IRR). IRR means the maximum interest rate possible to be repaid in the fixed period of one year, while one goes on repaying by using the benefit (profit) generated in a business where one has invested capital. The higher the interest rate, the lesser is the period of recovery of the invested capital, and in general, the project can be concluded to be a desirable one. Furthermore IRR is the discount rate by considering the present value of the business as 0 and it can be defined as *i* that satisfies Eq. (3).

Table 3 Basic units for damage cost of representative environmental pollutants.

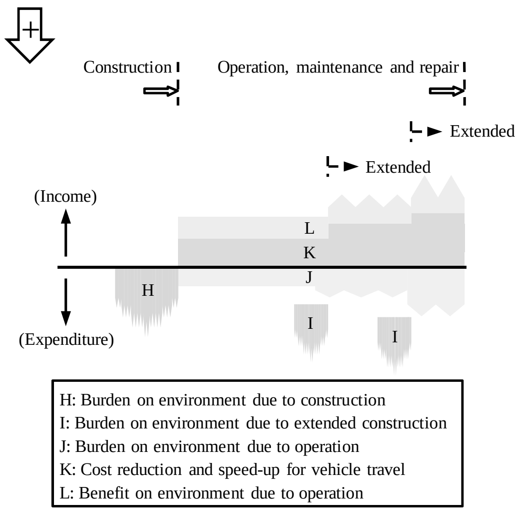
Environmental pollutants		Basic unit of damage cost	
Carbon dioxide	CO_2	2.6-9.6	(Yen/kg-CO_2)
Sulfur dioxide	SO_2	67.3-1,010	(Yen/kg-SO_2)
Nitrogen dioxide	NO_2	73.7-113	(Yen/kg-NO_2)
Methane	CH_4	16.9	(Yen/kg-CH_4)
Nitric oxide	N_2O	218	(Yen/kg-N_2O)
Ammonia	NH_3	403	(Yen/kg-NH_3)
Hydrogen chloride	HCL	175	(Yen/kg-HCL)
Floating particle	PM2.5	403-1,820	(Yen/kg-PM2.5)
Floating particle	PM10	2,450-11,100	(Yen/kg-PM10)



(a) Trilaminar structure of business cost and benefit



(b) Cost and benefit at implementation level
(Considering in calculation of FIRR)



(c) Cost and benefit at user and social level
(Considering in calculation of EIRR and $EIRR_{env}$)

Fig. 3 Cost and benefit analysis for subway construction project.

$$\sum_{t=1}^{n} \frac{(b_t - c_t)}{(1+i)^t} = 0 \qquad (3)$$

Here, t: chronological year, b_t: benefit in the period t, c_t: expenditure in period t and n: project life.

IRR can be classified into Financial Internal Rate of Return (FIRR) and Economic Internal Rate of Return (EIRR). FIRR is the internal rate of return concerning income of the business application base and it can be calculated only by considering: (1) mentioned above. On the other hand, EIRR can be calculated by considering (2) in addition to (4). Here, in Figs. 3b and 3c, the factors required to be considered for the calculation of FIRR and EIRR in the case of the subway business are shown. Moreover, in this paper, EIRR which can be calculated by considering up to the environmental cost (that is, EIRR calculated by considering (1), (2) and (3)) is described as $EIRR_{env}$. From Fig. 3, while implementing a business having highly a public nature (such as civil infrastructure), it is better to determine the contents of the business as one of the indices for deciding $EIRR_{env}$. For this, in the present assessment method, $EIRR_{env}$ of the business of civil infrastructure is calculated by considering the impact of the civil infrastructure project on the environment, by introducing the environmental cost in terms of money.

3. Burden and Benefit Following Bangkok Subway Project

In the Bangkok subway construction project, environmental pollutants are emitted from the material or fuel used for building and operating the Bangkok subway network. On the other hand, the Bangkok subway has brought about a shift in the means of travel from automobile traffic to railway travel and, as a result, there is expected to be a reduction in automobile traffic and also an increase in the speed of the automobiles in the surrounding area. From the standpoint of the environment of the construction of the Bangkok subway, in the operation stage, there is going to be a reduction in the quantity of emissions of environmental pollutants as compared to that before. Thus, the operation of the Bangkok subway is expected to bring about benefits for the environment. The above scenario is based on the baseline & credit concept in greenhouse gas emissions trading.

Table 4 shows a part of the factors related to the burden and benefits assumed in the Bangkok subway construction project, and it is essential to consider various items in the assessment of burden and benefits. In this assessment, the burden on the environment was restricted to emissions of environmental pollutants (CO_2, SO_2 and NO_2) caused by the material, fuel and electric power used in the construction and operation stages, while the benefits were restricted to the reduction in emissions of environmental pollutants resulted from reduction in automobile traffic in the surrounding area of the Bangkok subway project.

3.1 Bangkok Subway Construction Project

Before constructing the subway, 90% of the traffic of the Bangkok area was by road and traffic jams were a serious concern. For example, the average speed of a moving automobile was as slow as 8 km and economic loss due to the reduction in speed was said to be equivalent to 3% of the Gross Domestic Product (GDP) of Thailand. Furthermore, the road-dependent traffic caused severe air pollution due to the consumption of a large quantity of petroleum resources, so that the reduction of air pollution was also a big issue. The population of the Bangkok area was about 6.4 million in 2000 and it was estimated to increase to about 14 million by 2020. Thus, in the Bangkok area, the radical solution of traffic problems concerning automobile traffic was an immediate task.

As a means for solving the above problem, mass rapid transport was examined. As one of the national economic development plans, Thailand fixed a policy of providing a subway network in the Bangkok capital area and so MRTA started the Bangkok subway construction project in 1996, as the main construction body. The Bangkok subway construction project is proceeding even today. From July 3, 2004, it started the operation in a segment of the Bangkok subway Blue Line which makes use of a Yen-loan from Japan through the JBIC. The assessment of the burden and benefits to the environment conducted here is for the segment which started operation and extended over total 20 km and 18 stations (from Pharanpone to Bans stations) (Fig. 4). The period of operation of this segment is 6-24 hours and the time interval is 2-4 minutes during commute time and 4-6 minutes for others. The subway railroad cars have a total of 18 compositions (1 composition, 3 both coupled, capacity of 886 passengers). Assessment of the environmental burden and benefit of this segment is divided into two stages, namely, the construction stage for 1996-2004 and the operation stage from 2004.

The construction of this section was classified into a tunnel portion, station portion and railroad cars base. The tunnel portion was excavated with the sealed method, while the station portion was excavated by open excavation. Project cost of this section was totally about 360 billion Yen. For the civil engineering work of the tunnel portion, station portion and railroad car base portion, a loan of 220 billion Yen has been invested, whereas the management and business

Table 4 Factors relating to environmental burden and benefit assumed in Bangkok subway construction project.

	Burden on the environment	Benefit on the environment
Construction stage	(1) Production, transportation and consumption for materials, fuel, and electric power. (2) Concentrated mobilization of workmen. (3) Regulation of traffic in surrounding region (Promotion of congestion).	
Operation stage	(1) Generation, transportation and consumption for electric power. (2) Concentration of users.	(1) Reduction in traffic of car in surrounding region
Remarks: The object of environmental burden and benefit is an emission of environmental pollutants, a noise, a vibration and a stench.		

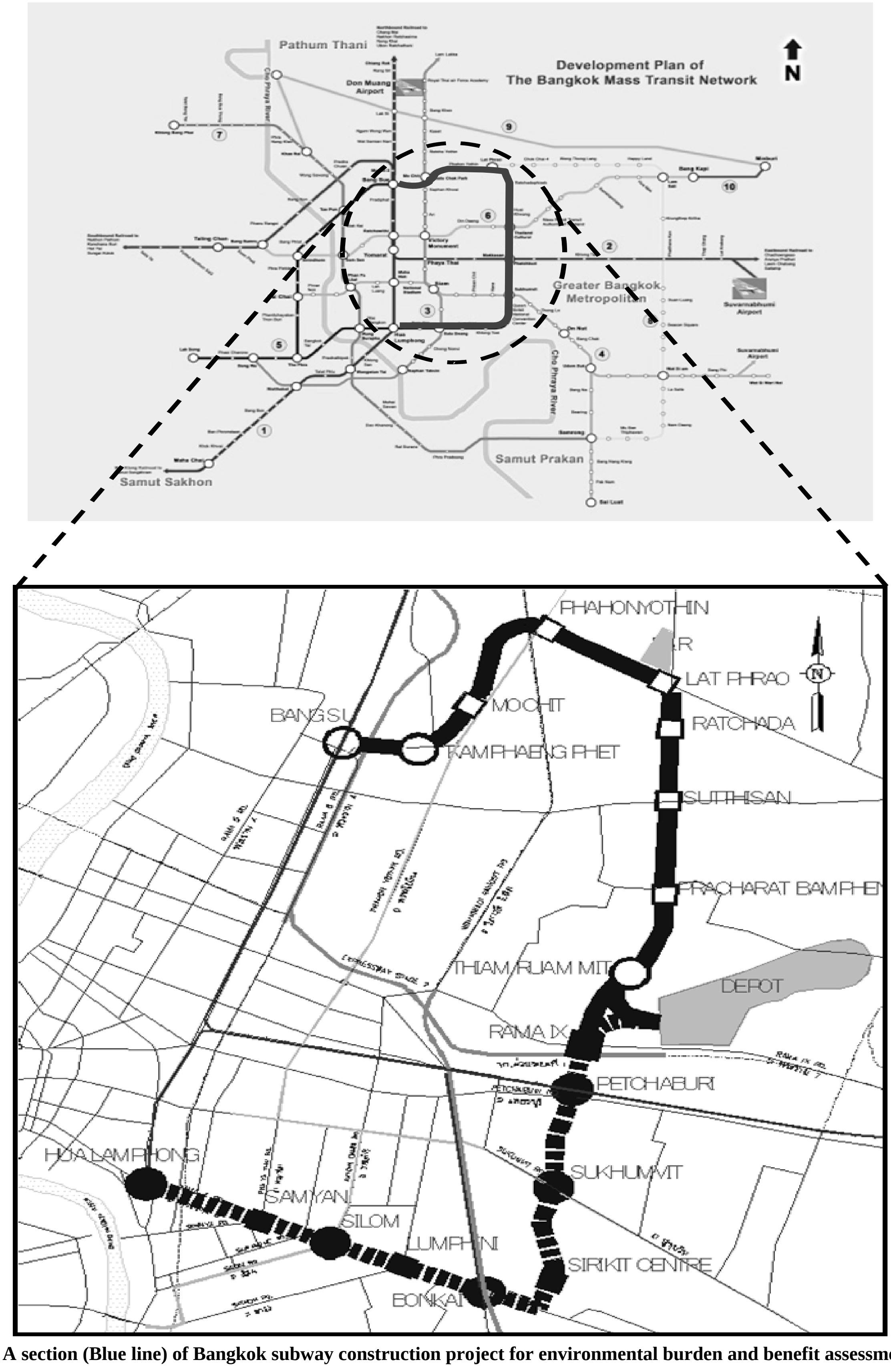


Fig. 4 **A section (Blue line) of Bangkok subway construction project for environmental burden and benefit assessment.**

administration of the Bangkok subway is entrusted to a private group for an effective period of 25 years.

3.2 Burden on the Environment in the Construction Stage

An estimation of the quantity of environmental pollutants (burden on the environment) in the construction stage of the Bangkok subway is done by dividing it into direct/indirect and direct environment-affected regions. Here, the object of the assessment in the construction stage was a tunnel portion, station portion and railroad cars base. The quantity of various materials, fuel and electric power used in the construction of the Bangkok subway project was as shown in Table 5, which is estimated from the budget report as well as the construction work schedule of the Bangkok subway project.

Table 6 shows the quantity of emissions of CO_2, SO_2 and NO_2 emitted to the direct/indirect and direct environment-affected region in the Bangkok subway construction stage. Here, the direct/indirect or direct environment-affected region is setup by expressing the emission coefficients of various materials, fuel and electric power in terms of Ei or eic (in case of electric power, eem+eef). From this, a comparison between the quantity of environmental pollutants (CO_2) in the direct/indirect environment region affected by the Bangkok subway construction (see Table 6) and the quantity of environmental pollutants (CO_2) separately obtained by calculation by using the emission coefficient integrated from various single civil infrastructures compiled from the literature (Table 7) shows that there is a not large difference in the emitted quantity of CO_2 and the estimated quantity of CO_2, and the emission of CO_2 can be considered to be at an appropriate level. Based on the above in Table 6, a major portion of the environmental pollutants in the construction stage of the Bangkok subway happens to be emissions in the material, fuel and electric power used in the production stage. Furthermore, the quantity of substances putting a burden on the environment in the direct environmental-affected region (see Table 6) is pproximately 1/10 of the total quantity of emissions in the direct/indirect environmental-affected region (see Table 6). Thus, the burden on the environment following the materials, fuel and electric power consumption is relatively smaller. Furthermore, for reducing the burden on the direct/indirect environment, it is important to use a material having a smaller emission coefficient for construction.

3.3 Burden and Benefits to the Environment in the Operation Stage

3.3.1 Burden on the Environment

The burden on the environment in the operation stage of the Bangkok subway is mainly due to electric power consumption. Total electric power consumption in the operation stage of the Bangkok subway, which includes subway running and incidental facilities is reported to be about 120×10^3 MWh (in 2005) [3]. The electric power consumption expenditure of the Bangkok subway is expected to increase following the number of trains running and number of coaches. Here, in the future estimate of electric power expenditure, the future trend of electric power consumption expenditure was predicted as shown in Fig. 5, by assuming that the electric power consumption expenditure will increase to the same extent as the future trend for expenditure for operation and maintenance estimated in the planning stage.

Table 8 shows the quantity of emissions of CO_2, SO_2 and NO_2 emitted to the direct/indirect and direct environment-affected region in the Bangkok subway operation stage. Here, as in the construction stage, the direct/indirect or direct environment-affected region is setup by considering the emission coefficient of electricity consumed in the operation, as E_i or $e_{em}+e_{ef}$. Considering the fact that the administration and operation is entrusted to a private group for an effective period of 25 years, the period of operation of the Bangkok subway (years of usage) is fixed to 30 years.

Table 5 Quantity of various materials, fuel and electric power used in the construction of the Bangkok subway project.

Materials						
		Interval (m)	Unit quantity used (t/m)		Total quantity used (× 10^3 t)	
			Concrete	Steel bar	Concrete	Steel bar
Underground tunnel						
Shield tunnel construction	Waste soil	32,003				
	Segment	32,003	12.7	0.9	406.4	28.8
Open cut tunnel (width: 25 m)	Waste soil	337				
	Backfilling	337				
	Diaphragm wall	337	134.4	12.2	45.3	4.1
	Slab	337	168.0	15.2	56.6	5.1
Open cut tunnel (width: 7.5 m)	Waste soil	190				
	Backfilling	190				
	Diaphragm wall	190	94.1	8.5	17.9	1.6
	Slab	190	43.7	4.0	8.3	0.8
Open cut tunnel (width: 5 m)	Waste soil	785				
	Backfilling	785				
	Diaphragm wall	785	94.1	8.5	73.9	6.7
	Slab	785	29.1	2.6	22.9	2.1
Open cut tunnel (width: 5 m)	Waste soil	66				
	Backfilling	66				
	Diaphragm wall	66	94.1	8.5	6.2	0.6
	Slab	66	42.6	3.9	2.8	0.3
Track slab						
Tunnel section	Concrete	32,003	2.2		70.4	
	Concrete	32,003	1.9		60.8	
	Reinforcing material	32,003		0.1		3.2
Station section	Concrete	4,644	9.4		43.7	
	Concrete	4,644	1.9		8.8	
	Reinforcing material	4,644		0.1		0.5
Underground station						
Station	Waste soil	4,644				
	Backfilling	4,644				
	Diaphragm wall	4,644	134.4	12.2	624.2	56.7
	Slab	4,644	168.0	15.2	780.2	70.6
Total					2,228.4	181.1

Electricity and fuel				
	Electricity consumption ratio	Normal power	Total running time	Electricity quantity used
Shield machine	0.429 (-)	1,000 (kW)	9.60×10^4 (hrs)	4.12×10^7 (kWh)
	Fuel consumption ratio	Normal power	Total running time	Fuel quantity used
Backhoe (small size)	0.175 (L/kWh)	100 (kW)	9.60×10^4 (hrs)	1.68×10^6(L)
Backhoe (large size)	0.175 (L/kWh)	250 (kW)	5.38×10^5 (hrs)	2.35×10^7 (L)
Clamshell	0.175 (L/kWh)	100 (kW)	3.52×10^5 (hrs)	6.16×10^6 (L)
	Fuel consumption ratio	One-way transportation distance	Transport sediment volume	Fuel quantity used
Dumper truck	0.0612 (L/km·t)	10 (km)	8.52×10^6 (t)	5.21×10^6 (L)

As can be seen in Table 8, in the direct/indirect and direct-affected region of the environment, in the 30-year-period ascertained as the assessment period, a large quantity of environmental pollutants is emitted as compared to that in the construction stage (see Table 6). Thus, although in the case of civil infrastructure, in general there is a tendency to pay attention to the burden on the environment in the construction stage, a comparison of Table 6 and Table 8 shows that a detailed study egarding the burden on the environment in the long-term operation stage is required, and it is necessary to do a comprehensive assessment by considering the construction and operation stages.

Table 6 Quantity of CO_2, SO_2 and NO_2 emitted to global and direct environment-affected region in construction of Bangkok subway.

Global environment-affected region							
	Quantity used W	CO_2 emission coefficient E_i	SO_2 emission coefficient E_i	NO_2 emission coefficient E_i	CO_2 emission quantity $E_i \times W$	SO_2 emission quantity $E_i \times W$	NO_2 emission quantity $E_i \times W$
Concrete	2,230 (× 10^3 t)	0.205 (t-CO_2/t)	0.099 (kg-SO_2/t)	0.461 (kg-NO_2/t)	457 (× 10^3 t-CO_2)	221 (t-SO_2)	1,028 (t-NO_2)
Steel bar	180 (× 10^3 t)	0.941 (t-CO_2/t)	1.496 (kg-SO_2/t)	3.376 (kg-NO_2/t)	170 (× 10^3 t-CO_2)	270 (t-SO_2)	608 (t-NO_2)
Fuel (Light oil)	36.6 (× 10^3 t)	3.000 (t-CO_2/kL)	4.390 (kg-SO_2/kL)	19.9 (kg-NO_2/kL)	110 (× 10^3 t-CO_2)	161 (t-SO_2)	728 (t-NO_2)
Electric power	41.2 (× 10^6 kWh)	0.564 (kg-CO_2/kWh)	0.461 (g-SO_2/kWh)	0.615 (g-NO_2/kWh)	23.2 (× 10^3 t-CO_2)	19.0 (t-SO_2)	25.3 (t-NO_2)
Total					760.2 (× 10^3 t-CO_2)	671.0 (t-SO_2)	2,389.3 (t-NO_2)
Remarks: Emission coefficient E_i in the table is based on Tables 1 and 2.							

Direct environment-affected region							
	Quantity used W	CO_2 emission coefficient e_{ic}	SO_2 emission coefficient e_{ic}	NO_2 emission coefficient e_{ic}	CO_2 emission quantity $e_{ic} \times W$	SO_2 emission quantity $e_{ic} \times W$	NO_2 emission quantity $e_{ic} \times W$
Concrete	2,230 (× 10^3 t)	0 (t-CO_2/t)	0 (kg-SO_2/t)	0 (kg-NO_2/t)	0 (× 10^3 t-CO_2)	0 (t-SO_2)	0 (t-NO_2)
Steel bar	180 (× 10^3 t)	0.941 (t-CO_2/t)	0 (kg-SO_2/t)	0 (kg-NO_2/t)	0 (× 10^3 t-CO_2)	0 (t-SO_2)	0 (t-NO_2)
Fuel (Light oil)	36.6 (× 10^3 t)	2.660 (t-CO_2/kL)	2.62 (kg-SO_2/kL)	17.6 (kg-NO_2/kL)	97.3 (× 10^3 t-CO_2)	95.9 (t-SO_2)	644 (t-NO_2)
Electric power	41.2 (× 10^6 kWh)	0.140 (kg-CO_2/kWh)	0.207 (g-SO_2/kWh)	0.350 (g-NO_2/kWh)	5.77 (× 10^3 t-CO_2)	8.53 (t-SO_2)	14.4 (t-NO_2)
Total					103.1 (× 10^3 t-CO_2)	104.4 (t-SO_2)	658.4 (t-NO_2)
Remarks: Emission coefficient e_{ic} in the table is based on Tables 1 and 2.							

Table 7 Quantity of CO_2 emitted to global environment-affected region in construction of Bangkok subway using emission coefficient integrated from various single civil infrastructures.

	Quantity used W	CO_2 emission coefficient E	CO_2 emission quantity $E \times W$ (×10^3 t-CO_2)
Main structure			
Shield tunnel	32,003 (m)	8.84 (t-CO_2/m)	283
Open cut tunnel	1,378 (m)	16.43 (t-CO_2/m)	22.6
Filling	328.2 (m)	6.49 (t-CO_2/m)	2.13
Attendant structure			
Slab track	57,476 (m)	0.29 (t-CO_2/m)	16.4
Underground station	18 (stations)	31,130 (t-CO_2/station)	560
Rail yard	1 (section)	6,123 (t-CO_2/section)	6.12
Rail car			
Aluminum Rail car	99 (carloads)	91.3 (t-CO_2/carload)	9.04
Total			899.3

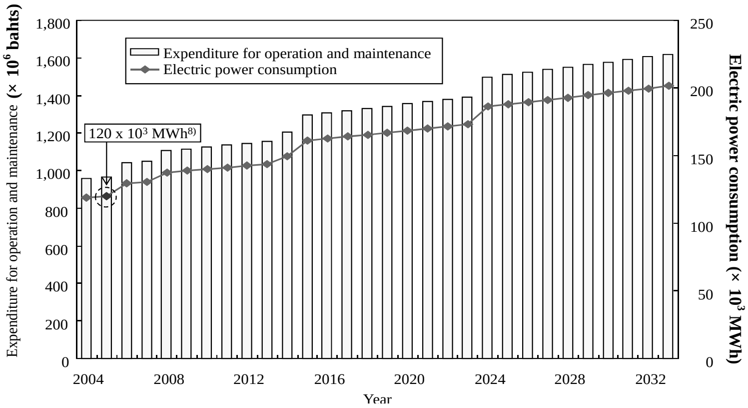


Fig. 5 Future estimation of electric power expenditure and electric power consumption expenditure.

Table 8 Quantity of CO_2, SO_2 and NO_2 emitted to direct/indirect and direct environment-affected region in operation of Bangkok subway.

Direct/indirect environment-affected region							
Year	Electricity quantity used W	CO_2 emission coefficient E_e	SO_2 emission coefficient E_e	NO_2 emission coefficient E_e	CO_2 emission quantity $E_e \times W$	SO_2 emission quantity $E_e \times W$	NO_2 emission quantity $E_e \times W$
2004	119 (× 10^6 kWh)	0.564 (kg-CO_2/kWh)	0.461 (g-SO_2/kWh)	0.615 (g-NO_2/kWh)	67.1 (× 10^3 t-CO_2)	54.9 (t-SO_2)	73.1 (t-NO_2)
2005	120 (× 10^6 kWh)	0.564 (kg-CO_2/kWh)	0.461 (g-SO_2/kWh)	0.615 (g-NO_2/kWh)	67.7 (× 10^3 t-CO_2)	55.3 (t-SO_2)	73.8 (t-NO_2)
(snip)							
2033	201 (× 10^6 kWh)	0.564 (kg-CO_2/kWh)	0.461 (g-SO_2/kWh)	0.615 (g-NO_2/kWh)	113.3 (× 10^3 t-CO_2)	92.7 (t-SO_2)	123.6 (t-NO_2)
Total					2,782.4 (× 10^3 t-CO_2)	2,274.3 (t-SO_2)	3,034.1 (t-NO_2)
Remarks: Emission coefficient E_e in the table is based on Table 2.							
Direct environment-affected region							
Year	Electricity quantity used W	CO_2 emission coefficient $e_{em} + e_{ef}$	SO_2 emission coefficient $e_{em} + e_{ef}$	NO_2 emission coefficient $e_{em} + e_{ef}$	CO_2 emission quantity $(e_{em} + e_{ef}) \times W$	SO_2 emission quantity $(e_{em} + e_{ef}) \times W$	NO_2 emission quantity $(e_{em} + e_{ef}) \times W$
2004	119 (× 10^6 kWh)	0.140 (kg-CO_2/kWh)	0.207 (g-SO_2/kWh)	0.350 (g-NO_2/kWh)	16.7 (× 10^3 t-CO_2)	24.6 (t-SO_2)	41.6 (t-NO_2)
2005	120 (× 10^6 kWh)	0.140 (kg-CO_2/kWh)	0.207 (g-SO_2/kWh)	0.350 (g-NO_2/kWh)	16.8 (× 10^3 t-CO_2)	24.8 (t-SO_2)	42.0 (t-NO_2)
(snip)							
2033	201 (× 10^6 kWh)	0.140 (kg-CO_2/kWh)	0.207 (g-SO_2/kWh)	0.350 (g-NO_2/kWh)	28.1 (× 10^3 t-CO_2)	41.6 (t-SO_2)	70.4 (t-NO_2)
Total					690.7 (× 10^3 t-CO_2)	1,021.2 (t-SO_2)	1,726.7 (t-NO_2)
Remarks: Emission coefficient E_e in the table is based on Table 2.							

3.3.2 Benefit to Environment

The benefit to the environment following the operation of the Bangkok subway is the reduction in environmental pollutants due to the reduction of automobile traffic and thus it is necessary to assess the quantity of emissions of environmental pollutants due to the automobile traffic.

Specifically, the relation between the average speed of automobiles and the quantity of fuel consumption can be sought from a chassis dynamo test and, by making use of the speed of automobiles, volume of automobile traffic and emission coefficient of the fuel (see Table 1) the effect on the quantity of emissions of environmental pollutants due to automobile traffic can be estimated. Here, Fig. 6 shows the typical relationship between the average speed of automobiles and the quantity of fuel consumed, as obtained from a chassis dynamo test. The information regarding automobile traffic and its running speed around the subway in the case when the Bangkok subway was constructed (mentioned as "with") and in the case when it was not constructed (mentioned as "without"), is essential.

Here, for the future estimate of automobile traffic (reduction) around the subway region in case of "with" or "without" a traffic model simulation, the 2004-2033 year shift in automobile traffic reduction (Fig. 7) estimated by Bangkok subway construction project authorities was referred to [3]. Here, the used traffic model simulation is known as eBUM (extended Bangkok Urban Model). When the consistency of the volume of traffic and traffic characteristics in the case of "with" and results from the traffic survey (traffic volume and traffic characteristics from Bangkok metropolitan administration) was checked, it led to a volume of traffic and its characteristics in the case of "without" [3].

On the other hand, on the basis of estimated reduction in automobile traffic in Fig. 7, and by supposing the running speed of automobiles to be a constant value of 25 km/h (Fig. 6), the reduction in fuel consumption quantity following the automobile traffic is shown in Fig. 8.

For confirming the appropriateness of the traffic

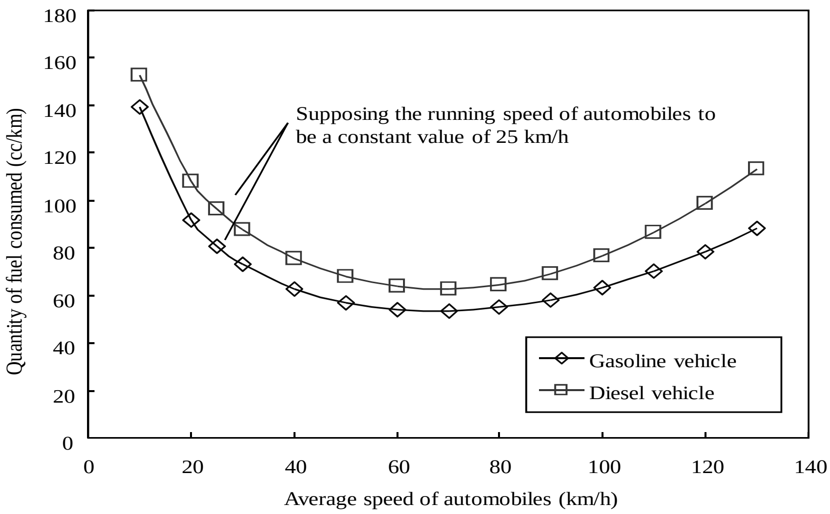


Fig. 6 Typical relationship between average speed of automobiles and quantity of fuel consumed.

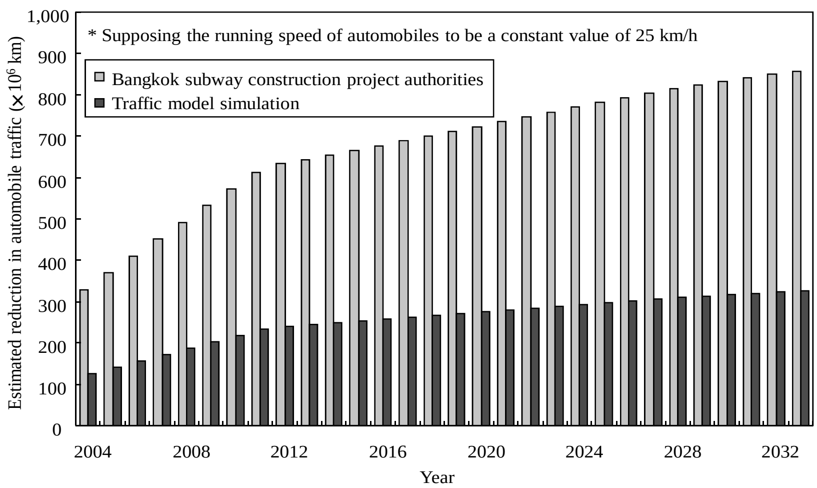


Fig. 7 Future estimation of reduction in automobile traffic around subway region.

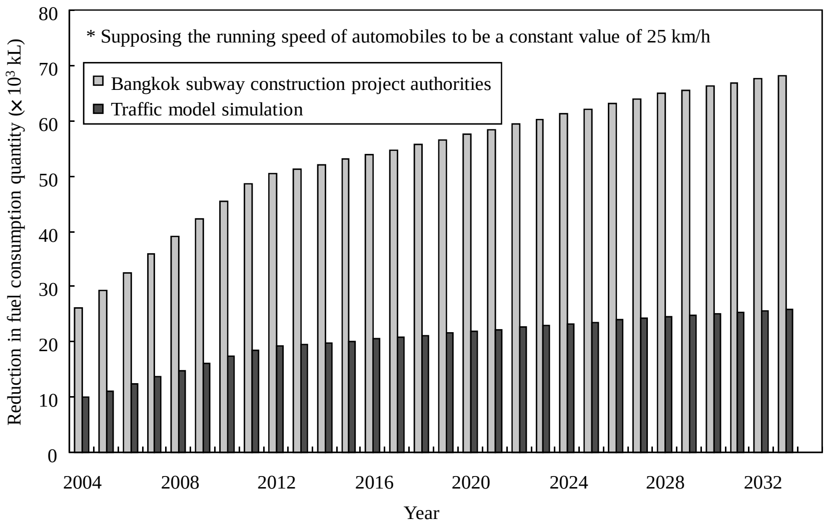


Fig. 8 Future estimation of reduction in fuel consumption quantity following the automobile traffic reduction.

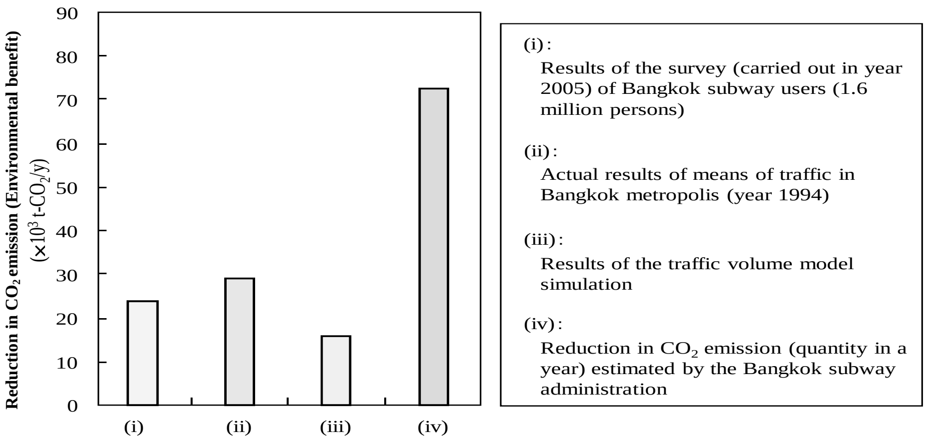


Fig. 9 Estimation of reduction in CO_2 emission using each method.

model simulation, Fig. 9 shows (1) results of the survey (carried out in year 2005) of Bangkok subway users (1.6 million persons) related to "means of traffic used before the opening of subway"; (2) actual results of means of traffic in Bangkok metropolis (year 1994); (3) traffic volume model simulation; and (4) final reduction in CO_2 emission (quantity in a year) originated from automobile traffic estimated by the Bangkok subway administration. This shows that the final reduction in CO_2 emission estimated from the traffic model simulation does not show an order of magnitude difference from the one obtained by other methods and it is suitable for estimating the reduction of the emission of environmental pollutants in future. Furthermore, by a simpler method of estimating the volume of automobile traffic from the number of subway users and by comparing the shift in tendency of volume of traffic based on a traffic model simulation for the years 2004-2007 also showed that the two agree in general.

Table 9 shows the quantity of reduction in emissions of CO_2, SO_2 and NO_2 emitted by automobiles into the direct/indirect and direct environment-affected region around the Bangkok subway, following the operation of the subway. For Table 9, it is presumed that the operating period (period of usage) of the Bangkok subway is 30 years and the reduction in fuel due to automobile traffic uses results in the model simulation results in Fig. 8. The direct/indirect and direct-affected region of the environment is established by expressing the emission coefficient of consumed fuel (gasoline) as E_i or e_{ic}.

Table 9 Quantity of reduction in CO_2, SO_2 and NO_2 emitted by automobiles into direct/indirect and direct environment-affected region following operation of Bangkok subway.

Direct/indirect environment-affected region							
Year	Reduction in fuel consumption quantity (gasoline) W	CO_2 emission coeficient E_i	SO_2 emission coeficient E_i	NO_2 emission coeficient E_i	CO_2 emission quantity $E_i \times W$	SO_2 emission quantity $E_i \times W$	NO_2 emission quantity $E_i \times W$
2004	9.9 (× 10^3 kL)	2.88 (kg-CO_2/L)	2.74 (g-SO_2/L)	6.08 (g-NO_2/L)	28.6 (× 10^3 t-CO_2)	27.3 (t-SO_2)	60.5 (t-NO_2)
2005	11.2 (× 10^3 kL)	2.88 (kg-CO_2/L)	2.74 (g-SO_2/L)	6.08 (g-NO_2/L)	32.2 (× 10^3 t-CO_2)	30.7 (t-SO_2)	68.0 (t-NO_2)
(snip)							
2033	25.9 (× 10^3 kL)	2.88 (kg-CO_2/L)	2.74 (g-SO_2/L)	6.08 (g-NO_2/L)	74.7 (× 10^3 t-CO_2)	71.1 (t-SO_2)	158 (t-NO_2)
Total					1,736 (× 10^3 t-CO_2)	1,680 (t-SO_2)	3,727 (t-NO_2)
Remarks: Emission coefficient E_i in the table is based on Table 1.							

Direct environment-affected region							
Year	Reduction in fuel consumption quantity (gasoline) W	CO_2 emission coeficient e_{ic}	SO_2 emission coeficient e_{ic}	NO_2 emission coeficient e_{ic}	CO_2 emission quantity $e_{ic} \times W$	SO_2 emission quantity $e_{ic} \times W$	NO_2 emission quantity $e_{ic} \times W$
2004	9.9 (× 10^3 kL)	2.32 (kg-CO_2/L)	0.0352 (g-SO_2/L)	2.57 (g-NO_2/L)	23.1 (× 10^3 t-CO_2)	0.350 (t-SO_2)	25.6 (t-NO_2)
2005	11.2 (× 10^3 kL)	2.32 (kg-CO_2/L)	0.0352 (g-SO_2/L)	2.57 (g-NO_2/L)	26.0 (× 10^3 t-CO_2)	0.394 (t-SO_2)	28.8 (t-NO_2)
(snip)							
2033	25.9 (× 10^3 kL)	2.32 (kg-CO_2/L)	0.0352 (g-SO_2/L)	2.57 (g-NO_2/L)	60.2 (× 10^3 t-CO_2)	0.913 (t-SO_2)	66.6 (t-NO_2)
Total					1,422 (× 10^3 t-CO_2)	21.6 (t-SO_2)	1,575 (t-NO_2)
Remarks: Emission coefficient e_{ic} in the table is based on Table 1.							

From Table 9), reduction of emissions (benefit to the environment) of environmental pollutants in the direct/indirect environment-affected region expected from the operation of the Bangkok subway is not an order of magnitude different as compared to that (burden on the environment) in the case of its operation as shown in Table 8. Thus, the operation of the Bangkok subway is not putting a large burden on the direct/indirect environment. However, the benefit to the environment in the direct region of the affected environment shown in Table 9 (reduction of environment-affective substances) is smaller as compared to direct/indirect environment-affected region (see Table 9). This may be attributed to the fact that in the production and circulation stage, the fuel shows a property of emissions of large quantities of SO_2 and NO_2 as compared to that in the consumption stage (see Table 1).

3.4 Bangkok Subway Construction Project with Introduction of Environmental Cost

In the case of the assessment of the burden and benefit to the environment concerning the Bangkok subway construction project, the quantity of environmental pollutants estimated in the construction and operation stages of the Bangkok subway was converted into an environmental cost by using the basic unit of damage due to the environmental pollutants, and the trial business assessment of the project was done from the consideration of an economic standpoint. This means that as stated in the chapter 2, the introduction of an environmental cost in the assessment of the Bangkok subway construction project done by considering the burden and benefit to the environment due to the civil infrastructure (that is, environmental accounting based on the burden and benefit to environment) is comprehensively understood up to the full course by adding the business (project) cost and lifecycle cost as shown in Fig. 3, for considering the social responsibility of the business itself. For the conversion of the quantity of emissions of environmental pollutants into the environmental cost, the basic unit quantity for the damage cost shown in Table 3 was used.

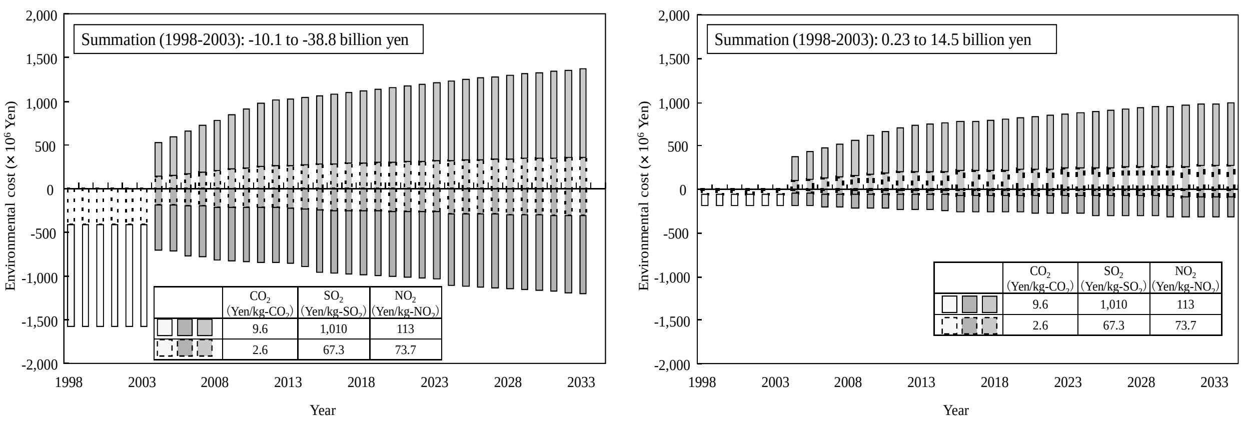
3.4.1 Change in Environmental Cost Following Construction and Operation

Fig. 10 shows the estimated quantity of emissions of environmental pollutants (CO_2, SO_2 and NO_2) in the direct/indirect and direct environment region concerning the Bangkok subway construction project as an environmental cost. In Fig. 10a, which assumes the direct/indirect environmental region in the Bangkok subway construction project, the environmental cost on operations for the overall period (which is assumed to be 30 years) is positive. That is, there is an overall benefit to the environment. However, the environmental cost of the construction stage is negative and, when the construction and operation stages are calculated, it is equivalent to the disbursement of an environmental cost of 10.1-38.8 billion Yen for the assumed period of 30 years of operation of the Bangkok subway. On the other hand, in Fig. 10b which shows the environmental cost for the direct environment-affected region, the environmental cost in the construction stage is less compared to that in the operation stage. Thus, when the construction and operation stages are calculated, it is the equivalent to an environmental cost of 2.3-14.5 billion Yen for the assumed period of 30 years of operation of the Bangkok subway.

As stated above, the environmental cost that has to be borne by the Bangkok subway construction project varies according to the setting of the environmental region. On the other hand, the environmental cost estimated in Fig. 10 can be presumed to be used as the index for deciding the feasibility of the Bangkok subway construction project. Thus, the index for deciding the feasibility of the project by considering the environmental cost, (which changes according to the setting of the environment region) is necessary and a trial calculation of $EIRR_{env}$ concerning the Bangkok subway construction project is done by considering the environmental costs shown in Fig. 10.

3.4.2 Economic Internal Rate of Return by Considering Environmental Cost

As stated in chapter 2, the Economic Internal Rate of Return is one of the indices for expenditure-benefit analysis sought on the basis of the social benefits of



(a) (b)

Fig. 10 Future estimation of environmental cost based on quantity of CO_2, SO_2 and NO_2 emitted to direct/indirect and direct environment-affected region in Bangkok subway construction project (a) Direct/indirect environment-affected region; (b) Direct environment-affected region.

the project. Here, in the Bangkok subway calculated by the main body, the subway establishment expenditure and the operation and maintenance expenditure were calculated as the expenditure and the reduction in running expenditure and reduction in time effects were calculated as benefits. As a result, the EIRR calculated for the construction stage and for 30 years operation of the Bangkok subway was 10.72% (see Table 10). Furthermore, the previously calculated EIRR=10.72% was more than the general standard for southeast Asia of 10% and thus the Bangkok subway construction project can be considered as a socio-economically effective project. As against the above, when the estimated environmental cost (see Fig. 10) is considered as the burden and benefit cost in EIRR calculation, the value of $EIRR_{env}$ = 10.54-10.73 is obtained (see Table 10). This also indicates the socio-economic appropriateness of the Bangkok subway construction project in the index of $EIRR_{env}$. In general, it can be concluded that in recent years where there is a growing concern about the environment, the Bangkok subway construction project is an appropriate project for considering the impact of environmental pollutants. Furthermore, the reason for the fact that the proportion of environmental cost caused by the Bangkok subway construction project in the overall project cost was very small, suggesting that there was no disparity between the previously calculated EIRR and $EIRR_{env}$, which considers the environmental cost.

As can be seen from the above, the proposed method of the assessment of the burden and benefit to the environment with the introduction of $EIRR_{env}$ can be used as one of the indices considering the impact on the environment in the establishment of civil infrastructure.

4. Conclusions

In this study, a method for the assessment of the burden and benefits, which contributes to the

Table 10 Calculation of EIRR and $EIRR_{env}$ considering with environmental cost.

Year	Cost (× 10^6 Baht)		Benefit (× 10^6 Baht)		Net benefits (× 10^6 Baht)	Environmental cost in Global (× 10^6 Baht)		Net benefits (× 10^6 Baht)	Environmental cost Direct (× 10^6 Baht)		Net benefits (× 10^6 Baht)
	Construction	Operation and maintenance	Speed-up for vehicle travel	Cost reduction for vehicle travel		Cost	Benefit		Cost	Benefit	
1998	-25,733				-25,733	-660		-26,393	-72		-25,805
1999	-16,905				-16,905	-660		-17,565	-72		-16,977
2000	-16,905				-16,905	-660		-17,565	-72		-16,977
2001	-1,869				-1,869	-660		-2,529	-72		-1,941
2002	-7,165				-7,165	-660		-7,825	-72		-7,237
2003	-19,406				-19,406	-660		-20,066	-72		-19,478
2004		-957	1,064	176	283	-70		213		13	296
2005		-965	1,286	197	518	-48		470		16	534
2006		-1,041	1,553	221	733	-45		688		18	751
2007		-1,050	1,875	247	1,072	-22		1,050		21	1,093
2008		-1,106	2,263	277	1,434	-14		1,420		24	1,458
2009		-1,116	2,729	311	1,924		2	1,926		27	1,951
2010		-1,126	3,291	348	2,513		5	2,518		29	2,542
(snip)											
2033		-1,620	225,882	4,801	281,483		11	281,494		45	281,528
Total					1,307,557			1,304,727			1,396,586
				EIRR = 10.72%			$EIRR_{env\_G}$ = 10.54%			$EIRR_{env\_L}$ = 10.73%	

assessment of civil infrastructure by considering the environment has been constructed. Furthermore, assessment of the Bangkok subway construction project was carried out by applying the proposed method, and trial project assessment with consideration to the environment was done. The results obtained were as follows.

A method for quantitative estimation of the burden and benefits to the environment has been proposed for the assessment of the impact of the civil infrastructure on the environment. In this method, it is possible to consider the direct/indirect environment-affected region and the impact on the environment can be quantitatively measured by using emission coefficients at different levels.

In the assessment of the impact of civil infrastructure on the environment, a method for conversion of the quantity of the burden and benefits into monetary terms by using the basic units of damage cost of environmental pollutants has been proposed. From this, it is possible to evaluate the impact of the civil infrastructure on the environment in monetary terms.

By applying the proposed method of assessment of the burden and benefits to the environment to the Bangkok subway construction project, it was possible to quantify the burden and benefits to the environment, in the life cycle of the Bangkok subway.

By converting the burden and benefits of the Bangkok subway construction project into monetary terms and introducing the Economic Internal Rate of Return (EIRR), it was possible to also consider the subway construction project from an economic point of view.

In this research, the industry-related method of analysis based on the industry-related chart of 1995 was used for setting up the emission coefficient of elements. On the other hand, in the case of overseas projects represented by the Bangkok subway construction project, it is necessary to study in detail the appropriateness of the emission coefficient and determination of emission coefficients of the elements confirming to the business site. At the same time, the basic unit of damage cost of the environmental pollutants is supposed to change with the region and time. In this research, although $EIRR_{env}$ is calculated by considering the basic unit of damage cost of the environmental pollutants as a constant; primarily the basic unit of damage expenditure has to be considered as a value that varies from time to time. From now onwards, it is necessary to establish a basic unit for damage cost of the environmental pollutants by using a procedure represented by the trading of CO_2 emissions. Finally, in the future there is a lot of uncertainty regarding the long-term use of the civil infrastructure. Therefore, there is a necessity for the assessment of the impact on the environment by considering uncertainty by using probability statistics.

Acknowledgments

This study was supported by grants from the Global Center for Education and Research on Human Security Engineering for Asian Megacities, Global Center of Excellence Program, Kyoto University.

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