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Green Assessment of Thailand's Highway Infrastructure: A Green Growth Index Approach

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Abstract

Infrastructure investment is considered to be one of the crucial factors for promoting economic growth. In developing countries such as Thailand, government spending on economic infrastructure is critically important. However, promoting economic growth through infrastructure spending is not without consequences. For instance, a significant amount of carbon emissions was released by the construction and operation of roads in recent years. The aim of this paper is therefore to present a new model of green growth assessment for highway infrastructure that combines economic index with environmental performance of the project. Unlike its contemporary methods, the proposed Green Growth Index (GGI) accounts for the fact that the actual performance of a road project, both economic and environmental ones, may be different from what had been predicted. Accordingly, it may be of use to periodically evaluate the performance of the project in terms of its economic benefits and environmental impacts. A hypothetical road project is first used as a numerical example to illustrate how the proposed method can be applied. Then, a real highway project called Kanchanaphisek Road is then employed as a case study project presented in this paper.

Keywords: *green growth, sustainability, economic evaluation, highway infrastructure*

1. Introduction

It is a well-known fact that investments in economic infrastructure such as bridges and roads are critically important for the long-term growth of a country. However, there may be undesirable consequences resulting from such investments in infrastructure. For instance, one of such prevalent consequences is the often destructive link between economic progress and the condition of natural environment. This may be because the construction of infrastructure projects, which usually take a few years to complete, would certainly bring with it pollutions. For example, several studies (e.g., Levin, 1997; Ding, 2005; Ding, 2008) found that the construction industry was highly responsible for the rapid depletion of natural resources and a major cause of environmental damages. Moreover, during the operation phase, certain types of infrastructure such as roads also create what is called "carbon intensive" activities, such as driving a personal car, instead of using public mass transit systems like metro buses and trains.

Therefore, it appears that, in order to promote economic growth, environmental degradation may be inevitable. In Thailand, it was estimated that the country would need to invest roughly 4.2 trillion baht in infrastructure projects during the period of 2014-2020 in order to compete in the current global market. Of this total, about 71 percent will be allocated to transportation projects (Kokkaew, 2016). Accordingly, it can be expected that the country may deplete its natural resources more rapidly in the coming years.

Currently, there are several economic evaluation methods such as the Net Present Value (NPV), the Benefit-cost Analysis (BCA), Economic Internal Rate of Return (EIRR) (Breadley *et al.*, 2010). As for the green assessment methods of a project, they include Leadership in Energy and Environmental Design (LEED), BCA Green Mark, and Greenroads Rating System.

However, as the notion of green growth is getting more interest, some may question the practical utility of it. For example, one may argue that the total costs of promoting the greenness of a project may outweigh the benefits to be received. Moreover, different countries may have different goals and objectives in pursuing their path to prosperity. For example, one of the goals set out by the Thai government is to become one of the world's top destinations for tourists (ranked at 14th in 2014, according to a report by UN World Tourism Organization), with an emphasis on sustainable tourism such as ecotourism. Thailand, however, also wants to position itself as manufacturing hub in the South East Asia, especially for the automobile industry. Therefore, it is interesting to pose a

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question of how the Thai government can do to balance between the two goals, that is, one is to be a manufacturing hub and another a world destination for tourism.

Although there are several methods designed specifically for either green assessment or economic evaluation, none is developed by combining economic performance of a project and its environmental indicator into a single index. This research is therefore to introduce a new index called "green growth" index. The proposed green growth index will be used for the evaluation of highway projects in Thailand and it can be periodically employed so as to measure the contemporary performance of the projects. This is in part because projects that receive green rating during the study stages may not perform as predicted. This is the question of performance risk that is ignored by most green assessment tools currently available.

The outputs of this research can provide the decision makers a framework on how to justify green investments in transportation projects that is considered cost-effectiveness. One of the implications of this research is that it could spur further investigation into how to make our overall infrastructure greener without compromising economic growth, as this latter goal tends to get more and more attention and influences our decision making processes which sometime takes a toll on our natural environment and resources. But, as we all know well, we cannot grow our economy indefinitely without exceeding our limited resources.

2. Carbon Emission in Transportation Sector

Several studies indicated that a large amount of carbon emissions was released from the transportation sector. Moreover, as the global economy continues to expand, it can also be expected that the amount of carbon emissions to be released by the transportation sector will only increase. For example, according to a study by the World Bank (2010), transportation accounted for about 14 percent of global greenhouse gas. The World Bank (2010) also reported that road transportation alone was responsible for as much as 72 percent of this total. In Asia, the total amount of carbon emissions from the transportation sector still keep growing. For example,

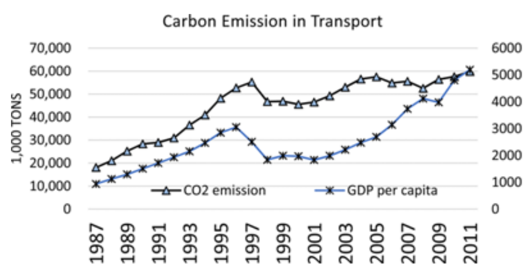

Fig. 1. Transportation Sector's CO2 Emissions Growth anD Economic Growth in Thailand (Source: Energy Statistics of Thailand 2012 (EPPO, 2012)

China, in 2013, released about 10.3 billion tonnes of carbon emissions, the highest in the world (Olivier *et al*., 2014). Meanwhile, Thailand released in 2011 almost 60 million tonnes of carbon emissions, as shown in Fig. 1.

3. Green Infrastructure Assessment

3.1 Green Infrastructure

Webster's New World Dictionary defined infrastructure as "the substructure or underlying foundation, especially the basic installations and facilities on which the continuance and growth of a community depends." Green infrastructure, which is based on the notion of green growth, is a term used to represent the idea of an attempt to improve the negative correlation between economic development and the evironment. The main argument of green growth is that the "grow-first-clean-up-later" approach to the economic development, as had been used by the industrialized countries, may not work for most of the countries (Shoots, Greens and Leaves, 2012). And, the reason is that the costs of cleaning up are increasing, making it almost impossible for a country to achieve what environmental economists call "economic-cum-environmental" (E1-cum-E2) development (Qingtao and Ludwig, 1999; Ludwig, 2006).

3.2 Methods and Tools of Evaluating the Greenness of Infrastructure

There are several methods developed for evaluating the greeness of infrastructure. For example, they Include Life Cycle Assessment (LCA), Leadership in Energy and Environmental Design, Comprehensive Assessment System for Building Environment Efficiency, the BCA Green Mark, and Greenroads (Wu and Low, 2010).

3.2.1 Life Cycle Assessment (LCA) Approach

Life-cycle Assessment (LCA) is a methodology developed to assess the environmental impacts associated with a product over its life cycle (Ross and Evans, 2002). It has been widely used in the last decade (Cicas *et al*., 2007). In practice, there are two major schools of thoughts regarding LCA: the International Organization for Standardization (ISO) and the United States Environmental Protection Agency (USEPA) (Ross and Evans, 2002). In academia, there are two approaches of LCA: process-based LCA and economic input-output analysis-based LCA (EIO-LCA). Process-based LCA is based on detailed process model descriptions and corresponding emissions and wastes, whereas economic input-output analysis-based LCA (EIO-LCA) is based on economic input-output data and publicly available resource consumption and environmental discharge data.

3.2.2 Leadership in Energy and Environmental Design (LEED)

Leadership in Energy and Environmental Design or LEED is a certification program developed by the U.S. Green Building Council for designing, constructing, and certifying green buildings

(Bayraktar and Owens, 2010). The goal of LEED is basically to promote practices that help limit the negative impact of buildings on occupants and the environment, as well as the economic returns of buildings (Boake and Prochazka, 2004). LEED is designed to apply to the design and construction of buildings of all sizes. To the author's knowledge, LEED has not yet been extended its scope into infrastructure projects.

3.2.3 Comprehensive Assessment System for Building Environment Efficiency (CASBEE)

CASBEE is developed and used in Japan. The CASBEE's main criteria include energy efficiency, resources efficiency, local environment and indoor environment (Horvat and Fazio, 2005; Alyami and Rezgui 2012). To evaluate how green and sustainable a building is, CASBEE simply adopts the value of BEE (Building Environmental Efficiency), which is given by the equation below (Mao *et al*., 2009).

$$BEE = \frac{Building\ \ Enivironmental\ \ Quality}{Building\ \ Environmental\ \ Loadings}$$

3.2.4 BCA Green Mark

BCA Green Mark for infrastructure, developed by the Building and Construction Authority of Singapore (www.bca.gov.sg), comprises of 6 categories, with totaling being 130 points: (1) Landscape, ecology and land efficiency; (2) Energy and renewable energy; (3) Water; (4) Project management; (5) Waste management and environmental protection; (6) Innovation (30 points). Rating scale for BCA Green Mark infrastructure is divided into 4 levels as shown in Table 1.

Table 1. Rating Scale for BCA Green Mark Infrastructure

Green Mark Points	Rating Level
90 and above	Platinum
80 - <90	Gold plus
70 - <80	Gold
50 - <70	Certified

Source: BCA Green Mark for Infrastructure Version 1.0 (2009)

3.2.5 Greenroads Rating System

Greenroads is a sustainability rating system of the design and construction of roadway and bridge projects (Anonymous, 2010). It is developed by the non-profit Greenroads Foundation. The scoring system provides projects 'credits' based on core project requirements such as (1) quality control, (2) noise mitigation, (3) waste management, (4) pollution prevention, (5) development impact minimization, (6) pavement management, and (7) site maintenance (Lemay, 2011).

3.2.6 Limitations of the Current Green Assessment Methods

Since there are many tools developed to assess green buildings and infrastructure projects, it is therefore tempted to think that there must be some studies that compare the pro and cons and the limitations of these methods. Fortunately, there is one recently published article by Alyami and Rezgui (2012). In their paper, environmental assessment methods, namely, LEED, BREEAM, and SBTool, are thoroughly compared. They then proposed criteria of environmental assessment method. One of the criteria relevant to our research study is economic aspects of the assessment methods. These economic aspects include (1) construction cost, (2) life cycle cost, (3) operating and maintenance cost, (4) investment risk, and (5) affordability of residential rental. Only SBTool meets all these criteria, whereas LEED and BREEAM address only operating and maintenance cost.

Furthermore, methods for green assessment have been designed to suit a specific type of projects. While the Greenroads rating system by the Greenroads Foundation was specifically designed for roadway and bridge projects, it ignores economic aspects in the evaluation of the projects. And what makes the economic aspects of the projects so important. The answer is that only the projects with positive economic impact should be developed so as to promote overall economic growth. Therefore, better green assessment methods should address not just how green the project is, but also how much its impact on the economy.

Another problem of the abovementioned green assessment methods was that these methods were designed for specific

Table 2. Drawbacks and Limitations of Current Methods for Green Assessment

Key aspects	LEED	CASSBEE	BCA Green Mark	Greenroads
Economic aspects (Kamaruzzaman, 2016)				
Construction cost	-	-	-	-
Life cycle cost	-	-	-	√
Operating and maintenance cost	√	-	-	-
Investment risk	-	-	-	-
Environmental aspects	√	√	√	√
– Sustainable site & ecology	√	√	√	√
– Energy efficiency	√	√	√	√
– Materials	√	√	-	√
– Pollution and risk	√	√	√	√
– Limitations and comments	These green rating systems lack of the integration of economic aspects into environmental sustainability. For Thailand who also wants to promote itself as a world's top destination for tourists, the aesthetic aspects of the highway projects should also be considered to provide a comprehensive outlook of how a green highway project is supposed to be for Thailand.			

purposes and might not be able to apply to other regions (Cole, 1998; Cooper, 1999; Crawley and Aho, 1999; and Kohler, 1999). For instance, as for Thailand who wants to promote its tourism industry to be one among the best in the world, it is undeniable that the aesthetic features of infrastructure projects also play a role in increasing the positive feedback of tourists. That is, there are spill-over benefits of being green (i.e., the benefits that other sectors receive from the investments in green, also known as trickle-down benefits). With this way of reasoning, it may therefore be incorrect to economically evaluate a project on a case-by-case basis.

These drawbacks and limitations (summarized in Table 2 below) of current methods for green assessment provide an opportunity for this research to develop a more appropriate method for the assessment of our road infrastructure. The balance of green and gray in design, construction, and operation will also be addressed. The proposed method will be designed to suit the data and information available for use in this research project, making the results of this research project more reliable and useful.

4. Economic Assessment

Economic assessment of road projects can be done in several ways. The most common methods for determining project's economic viability are based on the concept of Discounted Cash Flow (DCF). For example, net present value or NPV, Economic Internal Rate of Return (EIRR), Financial Internal Rate of Return (FIRR), and benefit cost ratio are commonly used metrics to assess project's economic and financial feasibility.

Roads are public assets that are difficult to assess their benefits directly, and analysts often uses benefit cost analysis to determine whether the project should be implemented. However, when these projects are implemented using toll mechanisms, cash flow in (revenue, or direct benefits) can be easily collected, and Discounted Cash Flow (DCF) can be employed to determine whether the project produce positive net cash flow to the project developer (equity contributors).

5. New Framework of Green Growth Index

5.1 Evolution of Infrastructure Performance

Infrastructure has a limited useful life, and it generally involves four main stages: (1) planning and design, (2) construction, (3) operation and maintenance, and (4) end of useful life. Therefore, during its operation, the performance, whether economic or environmental, of an infrastructure project may be different from what is anticipated at the outset of the planning and design of the project, making it a time-dependent variable.

In terms of economic performance, associated costs and benefits incurred throughout the life of the project may be depicted as shown in Fig. 2 and Fig. 3. During the evaluation stage, project economic may be estimated using tools such as Net Present Value (NPV) so as to determine if the project yield a positive

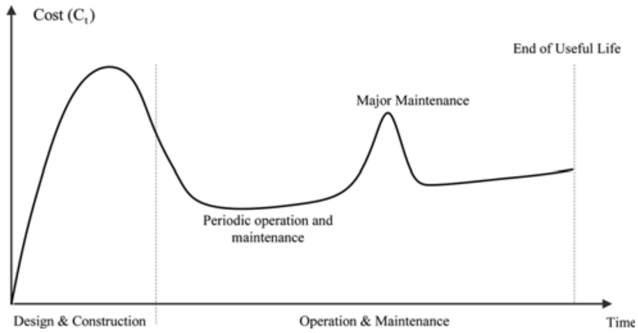

Fig. 2. Projected Performance of Project's Costs Thoughout its Life Cycle

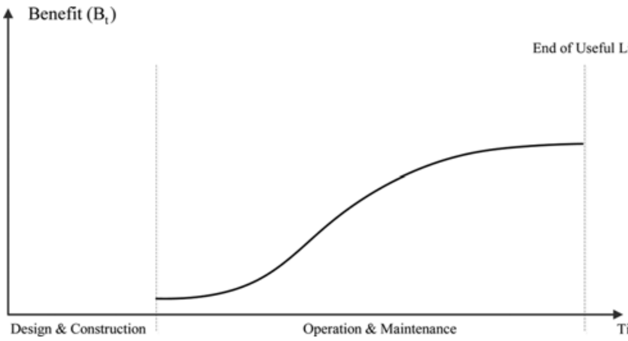

Fig. 3. Pojected Performance of Project's Benefits Thoughout its Life Cycle

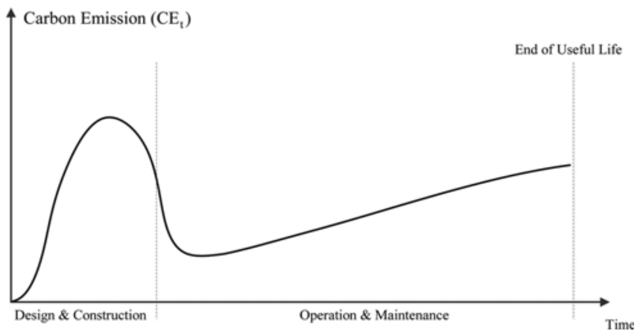

Fig. 4. Predicted Amount of Project's Carbon Emission Thoughout Its Life Cycle

NPV. However, the actual or real NPV of the project cannot be known with certainty in this stage because, in the future, the project is highly likely, in the presence of uncertainty, to produce different stream of costs and benefits, thereby yielding different NPVs. Therefore, reliance on the estimated and single point NPV could lead to an ill-informed decision making if only the actual NPV reveals to be below what had been estimated, or even worse, below zero, and that would be economically unacceptable.

Like costs and benefits associated with infrastructure projects, carbon emission released from all activities related to the project development, from planning to construction and to the operation, may be graphically depicted as shown in Fig. 4.

For the main reason that actual performance of the project may differ from what had been anticipated by analysts and planners, it may be useful to consider "evaluating" the project in a time-discrete manner, that is, we may use project's information available up until the present time as a basis for the calculation of project performance, and then decide what to do in the future with the project so as to achieve the desired targets such as to be economically and environmentally successful.

The concept of evaluating the performance of infrastructure projects over the life cycle is in line with Life Cycle Analysis (LCA), which is a systematic approach of looking at a project's complete life cycle. This idea provides the basis for this research to explore more on how the following ideas such as (1) to integrate economic performance into environmental one, (2) to provide a contemporary and hybrid index that can be used to assess the project at a discrete time interval, such as a one year time interval, (3) to see whether the project perform according to what it has been designed for, and (4) to provide a valuable guidance for project managers in particular on how to manage the project in the next period.

5.2 Computational Framework

Proposed in this paper is a new method called a green growth index for assessing the greenness of highway projects and its economic perfomance. Fig. 5 presents the conceptual framework of the green growth index and how the index is to be computed.

As can be seen in Fig. 5, during the operation phase, project owners can periodically determine the green growth index or *GGI* of the project. For example, assuming that the present time period is $t = j$ (See Fig. 5), evaluators can use project's information available up to the present time to compute the green growth index at time $t = j$, i.e., $GGI_{t=j}$. Note that this green growth index is also a time dependent variable, as a result its value may change over time depending on the actual performance of the project being managed. For example, if the project is redesigned to make it more environmental friendly by investing

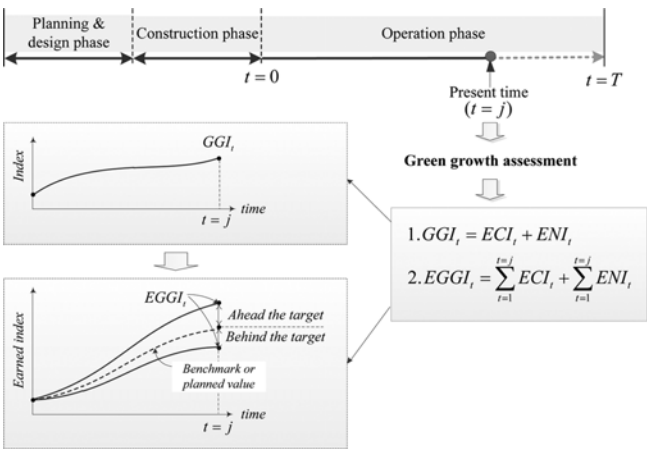

Fig. 5. Conceptual Framework of Green Growth Index (GGI) Assessment

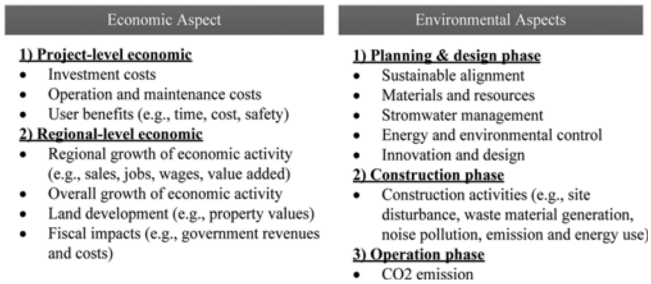

Fig. 6. Main Components of Economic and Environmental Aspects for Green Growth Assessment of Highway Projects

in improving certain components of the project, the environmental index (ENI_t) of this project should be increased. However, because of the money invested in this project, the project value may be reduced accordingly. Therefore, it is important to balance between these two objectives. The important question is how to optimally balance between the two.

Adopted from Soderlund (2007), the main components of economic and environmental aspects are shown in Fig. 6.

As previously shown in Fig. 5, Green-growth Index (GGI) can be computed by

$$GGI_t = ECI_t + ENI_t \tag{1}$$

where ECI_t and ENI_t is project's economic index and environmental index at time *t*, respectively. The ECI_t in Eq. (1) can be computed by

$$ECI_t = \frac{[B_t - C_t]}{A_t[\sum I]} \tag{2}$$

where ECI_t is economic index of the project in year *t*; B_t and C_t is total benefits (e.g., revenues) and total costs in year *t*, respectively; and, $A_t[\sum I]$ is the amortization of total investments over the useful life of the project. For example, if the total investment incurred during the 2-year construction phase is \$1000 million ($\sum I = 1000$) and the useful life of the project is 30 years, then, by assuming that the annual discount rate is 10%, the amount of this investment distributed over the 30-year useful life is \$106.08 million/year, i.e., $A_t[\sum I] = 106.08$. As for the ENI_t, it can be estimated using the following equation

$$ENI_t = \frac{BM_t}{X_t} \tag{3}$$

where BM_t is the benchmarking environmental damages of a similar project at time *t*, whereas X_t represents the total amount of environmental damages to be released by the project itself in year *t*. In this study, environmental damages are represented by the amount of carbon emission. This is because, according to a study by the World Bank (2010), carbon emission from transportation is considered to be a major cause of environmental degradation, representing about 14% of total greenhouse gas emissions. Moreover, in highly populated areas like Bangkok, carbon emission from transportation can be as high as 90% of Total Greenhouse Gas (GHG) emissions (Pitanuwat and

Sripakagorn, 2015).

Earned green-growth index of a given year ($EGGI_t$) is a cumulative green growth index, calculated using the following equation

$$EGGI_{t=j} = \sum_{t=1}^{t=j} ECI_t + \sum_{t=1}^{t=j} ENI_t \tag{4}$$

Where $\sum_{t=1}^{t=j} ECI_t$ is the summation of project's economic index from year 1 to year $t=j$, and $\sum_{t=1}^{t=j} ENI_t$ is the summation of project's environmental index from year 1 to year $t=j$.

6. Numerical Example Project

To illustrate how the proposed green growth assessment can be used in real practice, a hypothetical highway project is employed in this section. The example project took two years for construction and is assumed to be in its 10th year during the operation period (operational life of a road is 30 years). Construction cost is estimated to be around 8,000 million baht for a 4-lane highway with 200-km long.

Carbon emissions produced from road projects are of two kinds: (1) project CO2 (occurred through construction and operation of the project itself) and (2) induced CO2 (or traffic CO2) which occurred by road users. The amount of CO2 is estimated to be 1,107 tCO2eq./lane/km for construction and 50 tCO2eq./lane/km (Williams-Derry, 2007). For example, for this road with the construction of 2 years, the amount of CO2 expected to be released during the construction is therefore about $1,107 \times 4 \times 200/2 = 442,800$ tCO2eq./year. As for the operation period, operation and maintenance of the road can produce CO2 of about 50 tCO2eq./lane/km. Therefore, this example road will produce about 40,000 tCO2eq. ($50 \times 200 \times 4 = 40,000$). The amount of CO2 expected to be released from this project over the construction and the operation period can be presented as shown in Fig. 7.

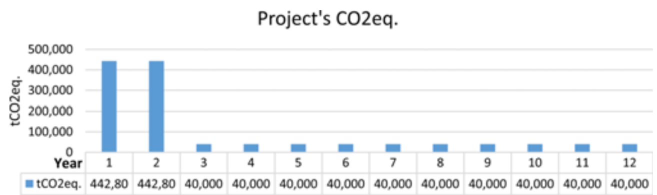

Fig. 7. Project's Carbon Emission Resulting from Construction and Operation of the Example Project

Table 3. Average Induced or Traffic Carbon Emissions (CO2) of Vehicle use in Thailand

Types of vehicle	Average carbon emission (g/km)	
	30 kph	60 kph
Motorcycle	33	29
Petrol Engine	178	129
Light Diesel	203	154
Heavy Diesel	821	577

Source: *Master Plan for Sustainable Transport and Climate Change Mitigation*

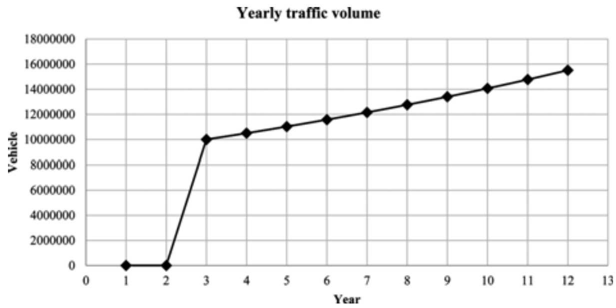

Fig. 8. Yearly Traffic Volume of the Road Project

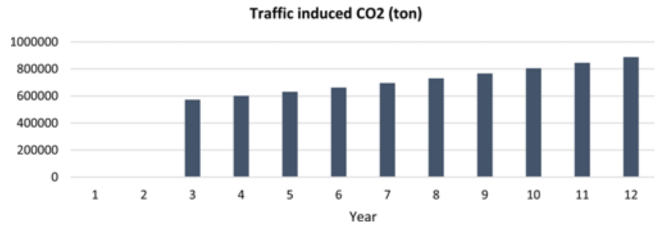

Fig. 9. Yearly Carbon Emission (induced CO2) from Vehicles using the Road

According to a report by the Office of Transport and Traffic Policy and Planning, the average induced or traffic CO2 emissions of vehicle use in Thailand is presented as shown in Table 3 (Office of Transport and Traffic Policy and Planning, 2013).

Traffic volume over the 10-year operation period is shown in Fig. 8.

For the illustration purpose, we assume that the amount of CO2 emission is the average of the amount of CO2 emission produced by petrol, light, and heavy diesel travelling at the speed of 60 km/hr, which is on average about 286.67 g/km. With this information, we can estimate the amount of traffic CO2 to be released during the operation period, as shown in Fig. 9.

As shown in Fig. 9, the amount of traffic CO2 gradually increased, from about 600,000 ton in the first year of the operation (year 3 in the time line) to about 900,000 ton in the final year (year 12 in the time line).

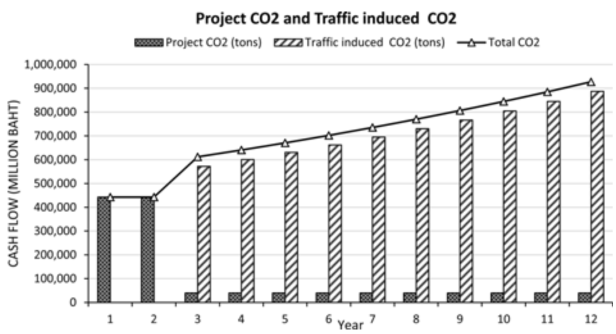

Fig. 10. Total Amount of CO2 over the Life Cycle of the Project (2 years for construction and 10 years for the operation)

Table 4. Relevant Information in Construction and Operation Phases

Year	Traffic volume	Construction (million THB) [I]	O&M costs (million THB) [C]	User benefits (million THB) [B]	Net income (million THB) [B]-[C]	Project's cash flow [B]-[C]-[I]
1		4,000			-4,000	-4,000
2		4,000			-4,000	-4,000
3	10,000,000		120	600	480	480
4	10,500,000		126	630	504	504
5	11,025,000		132	662	529	529
6	11,576,250		139	695	556	556
7	12,155,063		146	729	583	583
8	12,762,816		153	766	613	613
9	13,400,956		161	804	643	643
10	14,071,004		169	844	675	675
11	14,774,554		177	886	709	709
12	15,513,282		186	931	745	745
Total1	25,778,925					

Table 4. (continued)

Project CO2 (tons)	Traffic induced CO2 (tons)	Total CO2 emissions (tons)	Cumulative CO2 emission (tons)	Regional GPP (million THB)	Contribution to regoinal growth (million THB)*
442,800	0	442,800	442,800	40,000	400
442,800	0	442,800	885,600	42,000	420
40,000	572,000	612,000	1,497,600	44,100	441
40,000	600,600	640,600	2,138,200	46,305	463
40,000	630,630	670,630	2,808,830	48,620	486
40,000	662,162	702,162	3,510,992	51,051	511
40,000	695,270	735,270	4,246,261	53,604	536
40,000	730,033	770,033	5,016,294	56,284	563
40,000	766,535	806,535	5,822,829	59,098	591
40,000	804,861	844,861	6,667,690	62,053	621
40,000	845,105	885,105	7,552,795	65,156	652
40,000	887,360	927,360	8,480,155	68,414	684

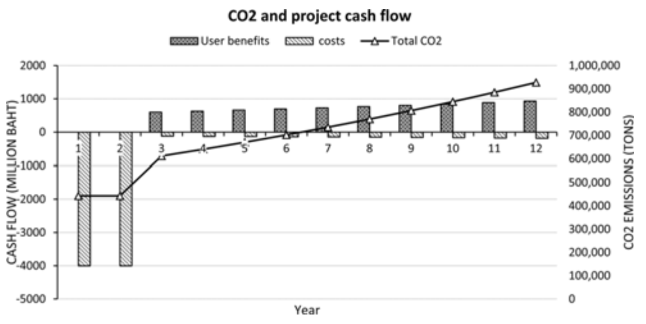

Fig. 11. Yearly CO2 Emission and Cash Flow of the Project

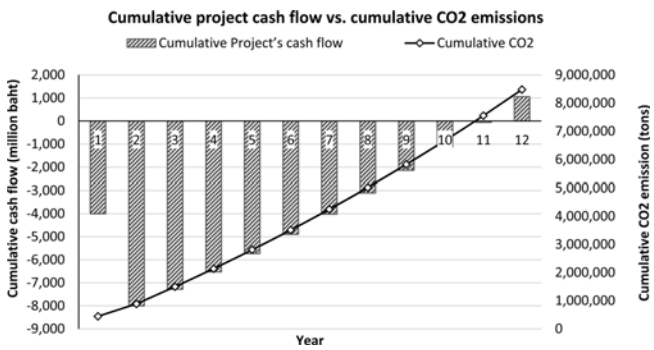

Fig. 12. Cumulative Project Cash Flow and Cumulative CO2 Emission

Total carbon emissions from this example project can be presented as shown in Fig. 10.

From Fig. 10, the total amount of CO2 estimated to be released from the project itself over the 12-year period was about 1.29 million tons, while the amount of CO2 forecasted to be released by road users over the 10 year-operation period was about 7.19 million tons. Therefore, over the life of this example road project, the total amount of CO2 expected to be released from all activities involved was about 8.48 million tons.

Other costs such as construction and operation and maintenance (O&M) are presented in Table 4 below. User benefits, net incomes, and hypothetical cash flow are also calculated as shown in Table 4.

From Table 4, we can graphically compare annual costs, benefits, and CO2 emissions as presented in Fig. 11 and Fig. 12.

Table 5. Benefit Cost Analysis of the Case Example Project

Year	Amortization of investment (million baht)	O&M costs (million baht)	Total costs (million baht)	Total benefits (million baht)	B/C ratio
1	520	120	640	600	0.94
2	520	126	646	630	0.98
3	520	132	652	662	1.01
4	520	139	659	695	1.05
5	520	146	666	729	1.10
6	520	153	673	766	1.14
7	520	161	681	804	1.18
8	520	169	689	844	1.23
9	520	177	697	886	1.27
10	520	186	706	931	1.32

By using the discount rate of 5%, the amortization of the investment cost of 8,000 million baht over a useful life of 30 years is about 520 million. The main reason why we use the amortization of the investment during the construction to be distributed over the operation period is because we want to disburse the investment through the operation period so as to compare total costs (investment cost plus operation and maintenance) with total benefit for each operating year. Therefore, if we compute the benefits and costs of the project during the operational life of 10 years, the results can be summarized, as shown in Table 5.

From Table 5, it is obvious that, after year 2, economic benefits of building the road far exceed the cost of construction and operation combined.

As for the environmental aspect, a benchmark CO2 emission from the study of ADB (ADB, 2010) was about 1,100 tons/km/lane/year. Therefore, for a 4-lane and 200 km long road, the amount of CO2 expected to be released from vehicles using this road was about 0.88 million tons per year. We can then calculate the green growth index (*GGI*) for each operating year as presented in Table 6, as well as the three indices (*ECI*, *ENI* and *GGI*), which is shown in Fig. 13.

As can be seen in Fig. 13, the green growth index of the case example project averaged around 2.3 (greater than 2.0), which is considered to be "favorable." If we look further into the two main components of the *GGI*, the *ECI*, the economic part of the index, increased steadily, while the *ENI*, the environmental component, decreased over time. Therefore, the contemporary performance of this example project is above a preferable economic level, whereas the current performance of its environmental impact is below the preferable level ($ENI_{t=12}$ = 0.95, which is below 1). As for the classification of the GGI of this example project, it would be considered to be the case of "growth but not green."

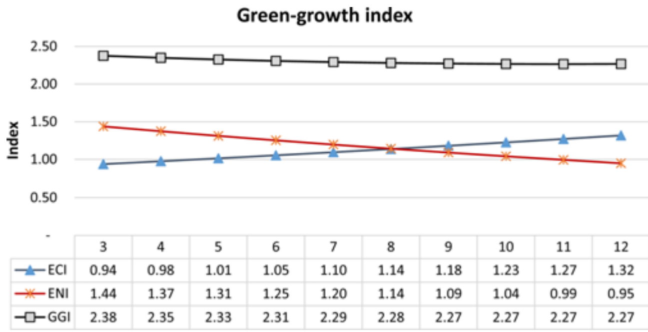

Fig. 13. Green Growth Index (GGI) of Case Example Project

7. Case Study Project: the Kanchanaphisek Road

Kanchanaphisek Road, formerly known as Motorway No. 9, is a 64-km outer ring road located in Bangkok. The initial investment made during construction was 12,000 million Thai baht (THB). Table 7 shows the information related to the construction and operation of the case study project.

Based on the information presented in Table 7, we can compute the economic index (ECI), the environmental index (ENI), the Green Growth Index (GGI), and the EGGI of the project for each year, from 1999 to 2013, as shown in Table 8.

8. Results and Discussions of the Case Project

Table 8 showed the results of green growth assessment of the case study project, the Kanchanaphisek Road. The GGI of the

Table 6. Analysis of GGI of the Case Example Project

Operational Year	Amortization of investment [A] (million baht)	Net economic benefit [B-C] (million baht)	ECI = [B-C]/[A]	Benchmark CO2 [BM] (Mt)	CO2 emissions [X] (Mt)	ENI = [BM]/[X]	GGI	EGGI
1	520	480	0.94	0.88	0.61	1.44	2.38	2.38
2	520	504	0.98	0.88	0.64	1.37	2.35	4.72
3	520	529	1.01	0.88	0.67	1.31	2.33	7.05
4	520	556	1.05	0.88	0.70	1.25	2.31	9.36
5	520	583	1.10	0.88	0.74	1.20	2.29	11.65
6	520	613	1.14	0.88	0.77	1.14	2.28	13.93
7	520	643	1.18	0.88	0.81	1.09	2.27	16.20
8	520	675	1.23	0.88	0.84	1.04	2.27	18.47
9	520	709	1.27	0.88	0.89	0.99	2.27	20.74
10	520	745	1.32	0.88	0.93	0.95	2.27	23.00

Table 7. Information Related to the Construction and Operation Phase of the Case Project

Year	Traffic volume	Construction (million THB) [I]	O&M costs (million THB) [C]	Revenues (million THB) [B]	Net income (million THB) [B]-[C]	Project's cash flow [B]-[C]-[I]
1996		**4,000**			**-4,000**	**-4,000**
1997		**4,000**			**-4,000**	**-4,000**
1998		**4,000**			**-4,000**	**-4,000**
1999	14,924,557		144	512	369	369
2000	22,950,525		299	788	489	489
2001	24,398,272		238	837	600	600
2002	28,934,657		53	993	941	941
2003	34,179,372		59	1,173	1,114	1,114
2004	40,439,965		90	1,388	1,298	1,298
2005	44,412,187		120	1,524	1,404	1,404
2006	43,891,384		157	1,507	1,350	1,350
2007	49,253,584		147	1,691	1,543	1,543
2008	50,191,094		119	1,723	1,604	1,604
2009*	53,926,203	**4,833**	135	1,851	1,716	6,549
2010*	61,263,227	**1,250**	136	2,103	1,967	3,217
2011	69,644,788		150	2,391	2,240	2,240
2012	70,449,196		159	2,418	2,259	2,259
2013E	116,843,441		136	4,011	3,875	3,875
Total	725,702,452			-		

*The project expanded from 4 lanes to 8 lanes

Table 7. (continued)

Year	Project's CO2 (tons)	Amortized Project's CO2 (tons)	Traffic induced CO2 (tons)	Total CO2 emission (tons)	Reginal GPP growth	Reginal transport GPP growth
1996	**94,464**				**8%**	**10%**
1997	**94,464**				**-4%**	**5%**
1998	**94,464**				**-4%**	**5%**
1999	12,800	18,468	96,160	**114,628**	4%	11%
2000	12,800	18,468	147,872	**166,340**	8%	6%
2001	12,800	18,468	157,200	**175,668**	8%	11%
2002	12,800	18,468	186,429	**204,897**	4%	7%
2003	12,800	18,468	220,221	**238,689**	7%	2%
2004	12,800	18,468	260,559	**279,026**	9%	6%
2005	12,800	18,468	286,152	**304,620**	9%	9%
2006	12,800	18,468	282,796	**301,264**	6%	-1%
2007	12,800	18,468	317,346	**335,814**	4%	-13%
2008	12,800	18,468	323,386	**341,854**	4%	3%
2009	**107,264**	18,468	347,452	**365,920**	0%	-2%
2010	**107,264**	18,468	394,725	**413,193**	6%	4%
2011	25,600	36,936	448,728	**485,664**	7%	2%
2012	25,600	36,936	453,911	**490,847**	-	-
2013E	25,600	36,936	752,834	**789,769**	-	-
Total	702,720		4,675,772			

case study project was graphically depicted as shown in Fig. 15. As illustrated in Fig. 15, the green growth index of the case study project as a whole has been gradually increasing. The Economic Index (ECI) of the case study project in recent years has gradually increased. However, the Environmental Index (ENI) of the case study project was deteriorating. For example, in 2013, it was estimated that the ENI of the case project would be 0.71, thereby indicating the poor environmental performance of the case project. Therefore, based on the results of this study, this case project, in its operational year of 15, should be characterized as "growth but not green." With this information, the project managers may decide to take action in managing the project in

Table 8. Results of Green Growth Assessment of the Case Study Project

Year	Amortization of investment [A] (million baht)	Net economic benefit [B-C] (million baht)	ECI = [B-C]/[A]	Benchmark CO2 [BM] (Mt)	CO2 emissions [X] (Mt)	ENI = [BM]/[X]	GGI	EGGI
1996	290							
1997	580							
1998	872							
1999	872	369	0.42	0.2816	0.1146	2.46	**2.88**	2.88
2000	872	489	0.56	0.2816	0.1663	1.69	**2.25**	5.13
2001	872	600	0.69	0.2816	0.1757	1.60	**2.29**	7.42
2002	872	941	1.08	0.2816	0.2049	1.37	**2.45**	9.88
2003	872	1114	1.28	0.2816	0.2387	1.18	**2.46**	12.34
2004	872	1298	1.49	0.2816	0.2790	1.01	**2.50**	14.83
2005	872	1404	1.61	0.2816	0.3046	0.92	**2.54**	17.37
2006	872	1350	1.55	0.2816	0.3013	0.93	**2.48**	19.85
2007	872	1543	1.77	0.2816	0.3358	0.84	**2.61**	22.46
2008	872	1604	1.84	0.2816	0.3419	0.82	**2.66**	25.13
2009	1236	1716	1.39	0.5632	0.3659	1.54	**2.93**	28.05
2010	1331	1967	1.48	0.5632	0.4132	1.36	**2.84**	30.89
2011	1331	2240	1.68	0.5632	0.4857	1.16	**2.84**	33.74
2012	1331	2259	1.70	0.5632	0.4908	1.15	**2.84**	36.58
2013E	1331	3875	2.91	0.5632	0.7898	0.71	**3.62**	40.21

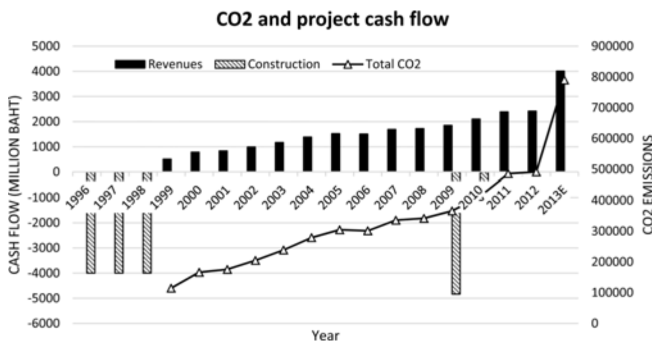

Fig. 14. Carbon Emission and Project's Cash Flow

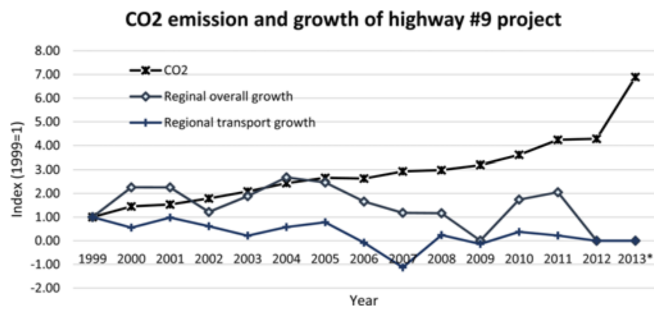

Fig. 16. Relationships between Economic Growth and Carbon Emission (CO2) of the Case Study Project

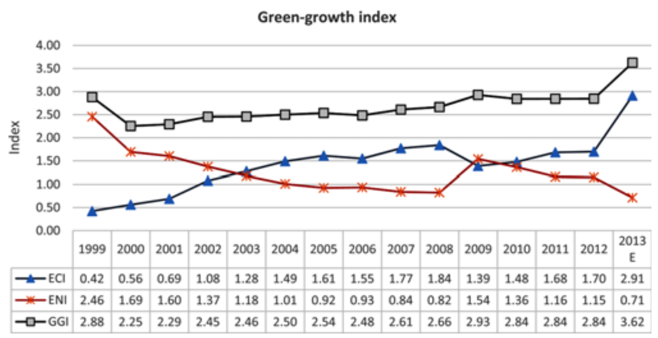

Fig. 15. Green Growth Index of the Case Study Project

the future so as to increase its economic contribution or to improve its declining environmental performance, or both.

9. Conclusions

This paper has presented a new framework of the green assessment called Green Growth Index (GGI). The aim of the proposed framework is to combine project environmental index and economic one into a single index that can be easily used by project managers. The GGI may help project managers in determining the "green growth" performance of the project being evaluated. In summary, we can spell out the results of any assessment using the proposed green growth index or GGI into four scenarios: (1) green and growth; (2) green but no-growth; (3) growth but not green; and (4) no-growth and not green.

Preferred result would obviously be the first scenario, "green and growth." The least preferable option would be a scenario in which both growth and green cannot be achieved. However, this scenario seems unlikely because "green" and "growth" are two opposing forces, i.e., higher economic growth of the project may translate into higher carbon emissions from the project accordingly. As the results of the case project showed, even though the GGI of the project floated above the threshold of 2 and gradually increased in recent years, the main contributor of the rising value of the index is economic one. Accordingly, this project may be labelled as a type of "growth but not green" scenarios.

The proposed Green Growth Index (GGI), unlike its contemporary methods, accounts for the fact that performance (either economic or environmental) of road projects may differ from what had been predicted. This situation is known as the evolution of the infrastructure through the passage of time over its useful life cycle. Accordingly, it may be of use to periodically evaluate the performance of the project in terms of its economic outputs and environmental impacts. Project managers and highway operators may use the results from using the proposed green growth assessment as a guideline in managing the project in the future. The proposed method can be adapted to assess other types of infrastructure projects with just a simple modification.

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