



Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/TRANPOL

Trends in Thailand CO₂ emissions in the transportation sector and Policy Mitigation

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ARTICLE INFO

Article history:

Received 15 January 2014

Received in revised form

19 September 2014

Accepted 20 January 2015

Keywords:

CO₂ emission

Transportation

Energy

Policy Mitigation

ABSTRACT

Daily human activities have caused severe impacts on global warming. Such human activities, in particular travel and freight transportation, generate massive emissions of greenhouse gases (GHGs), e.g., carbon dioxide (CO₂). Hence, the aim of this study was to predict the amount of CO₂ emissions from energy use in Thailand's transportation sector as well as related factors, thus providing a substantial benefit to determine policies for reducing GHG emissions and its impacts. In this study, 5 independent variables, namely the size of the population, gross domestic product (GDP), and the number of small, medium and large-sized registered vehicles, were considered in the forecasting of the CO₂ amount released from transportation energy consumption using 4 techniques: log-linear regression, path analysis, time series, and curve estimation. According to the findings, the time series exemplified the minimum mean absolute percent error (MAPE=5.388), followed by the log-linear regression model (MAPE=6.379). The results, based on a path analysis model, indicated the significant effects of the large-sized registered vehicle numbers, GDP, and population on the amount of CO₂ emissions. With the CO₂ emission forecast, the maximum predicted value was 225.33 million tons by 2030 using curve estimation (cubic), and the minimum predicted value was 91.68 million tons using log-linear regression.

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1. Introduction

Global warming and climate change are problems that face all people in the world (Al-mulali, 2012; Sözen et al., 2007). It is difficult to dispute that the transportation sector is one of the major causes because transportation energy consumption accounted for 1/5 of the total global energy use (Alsmann and Sieber, 2005; Ceylan et al., 2008; Meyer et al., 2007). By 2012, a massive amount of transportation-related energy use in Thailand was reported, accounting for 35.8% of the total domestic energy consumption and second only to energy use in the industrial sector (by only approximately 0.6%), as shown in Fig. 1. Energy Forecast and Information Technology Center, Energy Policy and Planning Office (2013) addressed the significant CO₂ emissions of 63.15 million tons generated by fuel consumption in which the transportation and traffic sector was responsible for the release of approximately 27% of GHG emissions from commercial energy consumption (Office of Transport and Traffic Policy and Planning,

2013), such emissions are a consequence of the driving force of transportation service in Thailand's economic and social development together with the continued growth of energy use in the sector (Limanond et al., 2011), which is similar to the growth in many countries, such as Spain (Climent and Pardo, 2007), Brazil (de Freitas and Kaneko, 2011; Pao and Tsai, 2011a), Greece (Hatzigeorgiou et al., 2011) and Canada (Hamit-Hagggar, 2012).

The increase in transportation consumption demand may affect the security of future energy procurement. Alongside the growing energy price trends, users can suffer from higher costs and lower economic competitive competencies as well as unfavorable balance of trade (Ministry of Energy, 2011; Yan and Crookes, 2009). In addition to the aforementioned problems, Thailand continues to face the environmental impacts caused by the use of transportation fuels, especially emissions of air pollutants, such as carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NO_x), particulate matter (PM), sulfur dioxide (SO₂), etc. Such pollutants are proven to be directly harmful to human health and are considered as a major cause of the urban climate deterioration that is affecting people (Colville et al., 2001; Dodić et al., 2009; Mazzarino, 2000). As evidenced in Bangkok, each year, hospitals in the city care for a

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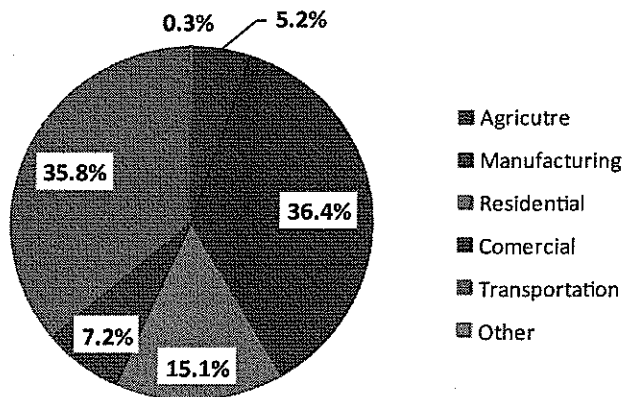


Fig. 1. Proportion of Thailand's 2012 energy consumption.

significant number of patient admissions with respiratory illnesses who live and work in polluted areas. Beyond the health impact regarded as a direct effect, transportation-related air pollution primarily causes greenhouse phenomena resulting from CO₂. The occurrence of such phenomena lead to changes in ecosystems, such as marine ecosystem transformation due to temperature increases that tremendously affect aquatic animal adaptations, thereby increasing the death rate. In fact, the more frequent occurrence of severe natural disasters has been driven by climate alteration, i.e., short winter and long summer periods. Moreover, if the global temperature rises, sea water and other water from various sources evaporates at a higher rate, leading to enhanced amounts of rainfall that can cause flooding in many areas. A major impact to Thailand was the 2011 flood crisis (starting from July 2011), which damaged a large area near the Chao Phraya and Mekong watersheds. In the last week of December 2011, 12.8 million villagers were affected, and the World Bank evaluated losses of up to 1.4 trillion THB, making the 2011 flood crisis one of the top 5 of the world's worst disasters in terms of damage (Mulsulin et al., 2012).

Hence, energy planning to reduce CO₂ emissions in the transportation sector is essential for enhancing the well-being of the environment at both the local and global community levels. Therefore, the purpose of this study is to propose a technique for predicting the amount of transportation-related CO₂ emissions and identifying the relevant factors. This study applies four statistical model development methods, including log-linear regression, path analysis, time series, and curve estimation, and then compares the efficiency between such models. Such research has not been previously performed. The knowledge and potential contributions based on the research can be integrated with transportation energy efficiency planning to provide environmental benefits as a consequence of air quality control in urban areas and GHG reduction in the atmosphere.

2. Literature review

The atmospheric greenhouse effect has greatly intensified the difficulties to people's lives in all countries. As a result, many studies related to factors affecting CO₂ emissions have been introduced. de Freitas and Kaneko (2011) specified that in Brazil, the amount of CO₂ discharge was directly influenced by economic and population growth. Likewise, case studies from this point of view were performed in various countries, e.g., Spain and other European countries (see more details in Table 1), MENA countries, Greece, Brazil, Lebanon, Canada, China, Malaysia, India, and ASEAN-5 (see Table 1). Ramanathan (2006), Climent and Pardo

(2007), Acaravci and Ozturk (2010), Al-mulali (2011), Hatzi-georgiou et al. (2011), Pao and Tsai (2011a), Dagher and Yacoubian (2012), Hamit-Haggar (2012), Pao et al. (2012), Saboori et al. (2012), Zhang et al. (2012), Chandran Govindaraju and Tang (2013), and Saboori and Sulaiman (2013) identified the effects of GDP and volume of fuel used on CO₂ emissions. Kumbaroglu et al. (2008) also verified that GDP and renewable electricity technologies affect the amount of CO₂ emitted.

In addition, a relationship between investment and financial variables and CO₂ release was identified by Pao and Tsai (2011b): the rate of energy consumption, GDP and FDI are associated with increasing CO₂ emissions in Brazil, the Russian Federation, India, and China. Similarly, Al-mulali (2012) used the case studies of Middle Eastern countries, namely Bahrain, Egypt, Iran, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the UAE, and Yemen, to identify such a relationship. Al-mulali and Binti Che Sab (2012b) and Al-mulali and Binti Che Sab (2012a) reported that energy usage, GDP, and financial development influence the CO₂ levels in Sub-Saharan African countries and 19 other countries (see more details in Table 1).

For emissions of CO₂ from the transportation sector, Sugihara et al. (2009) quantified the population density and identified a negative correlation with the number of passenger cars per capita and the road length per capita, while the length of road per capita exhibited positive impacts on the number of passenger cars per capita. In addition, the number of passenger cars per capita and the road length per capita positively influence the CO₂ emissions per capita. Limanond et al. (2011) reported that GDP directly affects the amount of energy consumed by the transportation sector. Similarly, Chandran and Tang (2013) found that GDP, FDI, and Transportation energy consumption directly influence the CO₂ emissions in Indonesia, Malaysia and Thailand.

3. Methodology

3.1. Data collection

This study used up-to-date data combined with data collected 24 years ago (from 1989 to 2012), including the gross domestic product (GDP) obtained from the Office of the National Economic and Social Development Board (2013), the size of the population from the Department of Provincial Administration (2013), the number of registered vehicles from the Department of Land Transport (2013), and the amount of transportation-related CO₂ emissions from the Energy Forecast and Information Technology Center, Energy Policy and Planning Office (2013).

A calculation of air pollutant emissions involves the estimation of the amount of CO₂ released from energy use in the nation. The Energy Policy and Planning Office (2011) calculated the CO₂ emissions from energy consumption and the emission factors of fossil fuel types via referencing the method of estimation and emission factors following the 2006 Intergovernmental Panel on Climate Change (IPCC) criteria. The formula is as follows:

$$\text{CO}_2 \text{ emission} = \sum (\text{EF}_{\text{Fuel}} \times \text{FC}_{\text{Fuel}}) \quad (1)$$

where CO₂ emission is the amount of CO₂ released from energy consumption, EF_{Fuel} is the CO₂ emission factor by fossil fuel types (based on the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories) and FC_{Fuel} is the amount of fuel consumed by each fuel type (based on the energy statistics database of the Energy Policy and Planning Office).

Regarding Fig. 2, the levels of CO₂ emissions in the transportation sector increased from 25.20 million tons in 1989 to 55.24

Table 1
Previous studies on the factors affecting CO₂ emissions.

Author(s)	Country	Period	Data	Methodology	Scale/sector	Key finding(s)
Ramanathan (2006)	World	1980–2001	GDP, energy consumption and carbon dioxide emissions	Data Envelopment Analysis (DEA)	World/all sectors	The effects of GDP on energy consumption and CO ₂ emission
Climent and Pardo (2007)	Spain	1984–2003	Gross domestic product (GDP) and energy consumption (EC)	Multivariate co-integration analysis	Country/all sectors	GDP showed direct and positive impacts on energy consumption
Kunbaroglu et al. (2008)	Turkey	2000	CO ₂ , GDP and renewable electricity technologies (RETS)	aggregate economic equilibrium analysis	Country/all sectors	Economic growth and technological change were associated with CO ₂ levels
Sugihara et al. (2009)	Japan	1999–2003	Population density, number of private car per capita, road length per capita, and car CO ₂ per capita	Structural Equation Modeling: SEM	Metropolitan employment area /transportation	(1) Population density has negative impacts on number of passenger cars per capita and road length per capita (2) Road length per capita has positive influences on number of passenger cars per capita (3) Number of passenger cars per capita and road length per capita have positive effects on CO ₂ levels per capita
Acarawi and Ozturk (2010)	Europe ^a	1960–2005	Carbon emissions per capita, energy consumption per capita, real gross domestic product (GDP) per capita	Causality analysis	Country/all sectors (analyzing each country separately)	Energy consumption per capita and real GDP per capita have effects on carbon emissions
Al-mulali (2011)	MENA countries	1980–2009	CO ₂ emission, GDP, and oil consumption	Panel model	Country/all sectors	Oil consumption ↔ CO ₂ GDP ↔ oil consumption GDP ↔ CO ₂
de Freitas and Kaneko (2011)	Brazil	1970–2009	CO ₂ emissions, energy consumption	Log-mean division index (LMDI)	Country/all sectors	A change in CO ₂ emissions was greatly affected by economic activities and population growth
Hatzigeorgiou et al. (2011)	Greece	1997–2007	Gross domestic product, energy intensity, and CO ₂ emissions	Multivariate co-integration and causality analysis	Country/all sectors	GDP and energy intensity have direct effects on CO ₂ emissions in the long term GDP ↔ CO ₂
Limanond et al. (2011)	Thailand	1989–2008	Transportation energy demand, number of vehicle registrations, GDP, population	Log-linear regression, Artificial neural network	Country/transportation sector	Energy intensity ↔ CO ₂ GDP has positive influences on amount of energy consumption in the transportation sector
Pao and Tsai (2011b)	BRIC (Brazil, Russian Federation, India, and China)	1980–2007	CO ₂ emissions, energy consumption, FDI (foreign direct investment), and GDP (gross domestic product)	Multivariate Granger causality	Country/all sectors	For long-term: GDP → FDI GDP ↔ CO ₂ GDP ↔ EC EC → CO ₂ CO ₂ ↔ FDI EC → FDI
Pao and Tsai (2011a)	Brazil	1980–2007	CO ₂ emissions, energy consumption, and real GDP	Linear logarithm quadratic form, grey prediction theory, ARIMA	Country/all sectors	Energy consumption and real GDP have a direct relationship with CO ₂ emissions in the long term EC ↔ GDP CO ₂ ↔ EC GDP ↔ CO ₂ EC ↔ CO ₂ GDP ↔ FD CO ₂ ↔ FD EC ↔ FD
Al-mulali and Binti Che Sab (2012b)	Sub-Saharan African Countries	1980–2008	Energy consumption, CO ₂ emission on GDP, and the financial development (FD)	Panel model	Country/all sectors	
Al-mulali and Binti Che Sab (2012a)	19 countries ^b	1980–2008	Energy consumption, CO ₂ emission, financial development (broad money, domestic credit provided by banking sector, domestic credit to private sector), and economic development (GDP per capita based on the purchasing power parity)	Panel unit root test, Pedroni (Engle-Granger based) co-integration tests, Panel Granger causality	Country/all sectors	Energy consumption and CO ₂ emissions showed a long-term relationship with the financial development indicator and the economic development indicator

Table 1 (continued)

Author(s)	Country	Period	Data	Methodology	Scale/sector	Key finding(s)
Al-mulali (2012)	Middle Eastern countries, namely Bahrain, Egypt, Iran, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the UAE, and Yemen	1990–2009	Energy consumption, FDI, GDP, and CO ₂ emission	Panel data analysis	Country/all sectors	Energy consumption, GDP, FDI net inflows, and total trade were considered as crucial factors affecting increases in CO ₂ emissions in the long term
Dagher and Yacoubian (2012)	Lebanon	1980–2009	Energy consumption and real GDP	Causality tests, namely, Hsiao, Toda–Yamamoto, and vector error correction-based Granger causality tests Panel co-integration analysis	Country/all sectors	For both short-term and long-term periods: energy consumption ↔ real GDP
Hamit-Haggar (2012)	Canada	1990–2007	Greenhouse gas emissions, energy consumption, and economic growth	Autoregressive integrated moving average (ARIMA) linear model, the nonlinear grey prediction model Co-integration analysis	Country/industrial sectors	There is a long-term relationship between greenhouse gas emissions and energy consumption There is a long-term relationship between emissions, energy consumption and real GDP
Pao et al. (2012)	China	1980–2009	CO ₂ emissions, energy consumption, and real GDP	Co-integration analysis	Country/all sectors	Gross domestic product (GDP) has direct influences on CO ₂ emissions CO ₂ emission per capita unit GDP reflects impact of economic growth and population Long-term relationship in Indonesia: GDP ↔ CO ₂ GDP ↔ FDI EC → GDP CO ₂ ↔ FDI EC → CO ₂ EC → FDI
Saboori et al. (2012)	Malaysia	1990–2007	Economic growth, energy consumption, and CO ₂ emissions	Evaluate the comprehensive performances	Country/all sectors	Long-term relationship in Malaysia: GDP ↔ CO ₂ GDP ↔ FDI FDI → CO ₂ GDP ↔ EC GDP ↔ FDI
Zhang et al. (2012)	China	1990–2009	Per capita CO ₂ emissions, per capita energy consumption for road transportation sector, per capita real foreign direct investment (FDI), and per capita real GDP	Co-integration and Granger causality	Country/transportation	Long-term relationship in Thailand: GDP ↔ CO ₂ FDI → GDP EC → GDP FDI → CO ₂ CO ₂ ↔ EC Long-term: GDP → CO ₂
Chandran Govindaraju and Tang (2013)	China and India	1965–2009	CO ₂ emissions, GDP, and coal consumption	Co-integration analysis	Country/all sectors	
Saboori and Sulaiman (2013)	ASEAN-5 ^c	1971–2009	GDP per capita, CO ₂ emissions per capita and per capita, and energy consumption	Autoregressive Distributed Lag (ARDL) methodology and Granger causality test based on vector error-correction model (VECM)	Country/all sectors (analyzing each country separately)	CO ₂ ↔ EC CO ₂ ↔ GDP GDP ↔ EC

Note: → denotes the direction of the causal relationship, and ↔ denotes a bi-directional causal relationship.

^a Europe includes Denmark, Germany, Greece, Iceland, Italy, Portugal, and Switzerland.

^b 19 countries, namely Antigua and Barbuda, Australia, Canada, China, Cyprus, Denmark, Iceland, Japan, South Korea, Malaysia, Malta, New Zealand, South Africa, St. Kitts and Nevis, Sweden, Switzerland, Thailand, United Kingdom, and the United States.

^c ASEAN-5, namely Malaysia, Indonesia, Singapore, the Philippines, and Thailand.

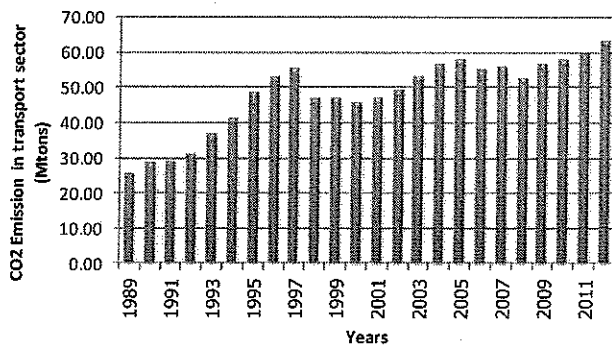


Fig. 2. The statistics of CO₂ concentrations in the transportation sector from 1989 to 2012.

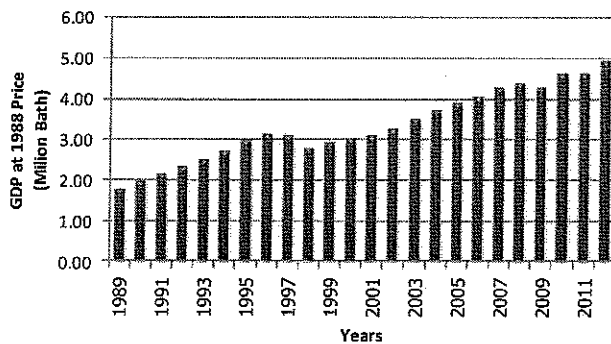


Fig. 3. GDP statistics from 1989 to 2012.

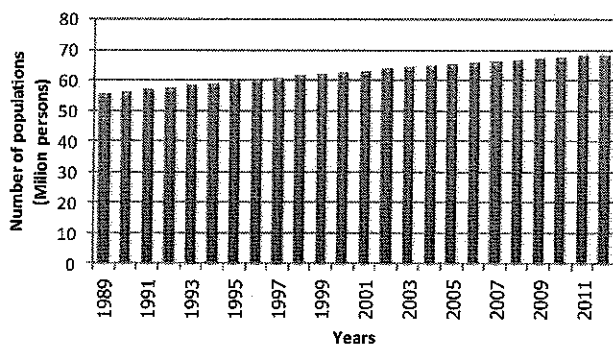


Fig. 4. Thai population from 1989 to 2012.

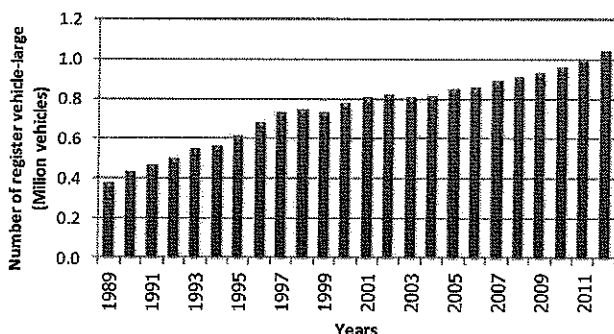


Fig. 5. Number of large-sized registered vehicles from 1989 to 2011.

million tons in 1997 before decreasing in 1998, which corresponded to the period of Thailand's economic crisis. Subsequently, CO₂ emissions tended to increase until 2012, with CO₂ amounts of 63.15 million tons released. The trend of GDP exhibits the same characteristics as those of CO₂ levels: in 2012, Thailand's GDP was

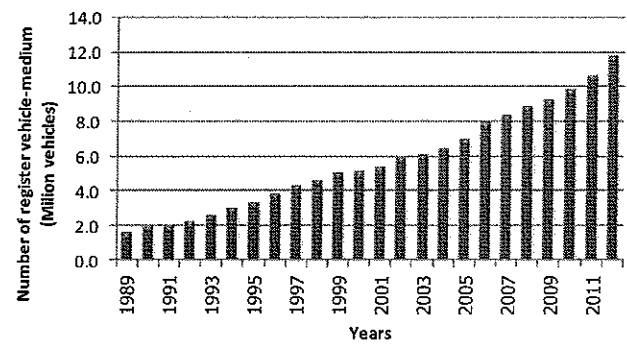


Fig. 6. Number of medium-sized registered vehicles.

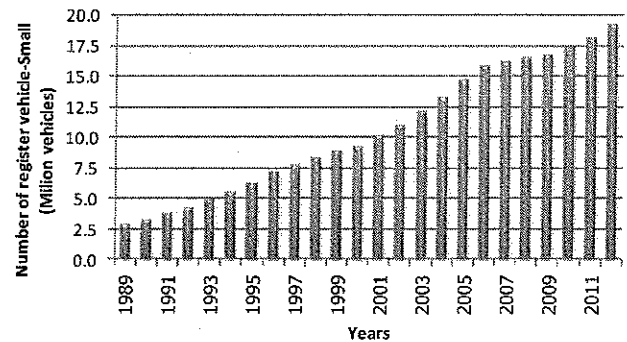


Fig. 7. Number of small-sized registered vehicles.

equivalent to 4.9 billion THB (in 1988 prices), as illustrated in Fig. 3. Furthermore, the population increased by 64.50 million from 1989 to 2012, and the numbers of large-, medium- and small-sized vehicles continuously increased from 1989 to 2012 by 19.17, 11.71, and 1.04 million vehicles, respectively, as demonstrated in Figs. 4, 5, 6 and 7.

3.2. Analysis methods

In this study, 4 techniques were selected by researchers for data analysis and the forecast process: log-linear regression, path analysis, time series, and curve estimation. Each of these techniques has a different procedure, as presented in Table 2. The log-linear regression analysis involves finding the relationship between independent variables ($X_1, X_2, \dots, X_n$) and a dependent variable (Y) in the form of a logarithm. The general formula of log-linear regression can be written as follows:

$$\ln(Y) = \beta_0 + \beta_1 \ln(X_1) + \beta_2 \ln(X_2) + \dots + \beta_n \ln(X_n) + \epsilon \quad (2)$$

Path analysis is a statistical method using the application of regression analysis to elucidate the influences of several independent variables on a dependent variable in both direct and indirect relationships as well as to explain the directions and levels of relationships of the variables.

The next technique applied in the analysis is the time series method, which involves the examination of the changes in the data during the period of the study to predict or estimate the future values using a forecasting technique to provide a suitable pattern based on the past data. The study used Expert Modeler in SPSS 16.0 to find a fitted-forecasting model between the exponential smoothing curve and the autoregressive integrated moving average (ARIMA).

Finally, curve estimation was introduced to the analysis to estimate a function value according to the past data containing 10 considered forms of linear, logarithmic, inverse, quadratic, cubic, compound, power, S, growth, and exponential functions as numerical methods.

Table 2

A comparison of the methods used in the analysis.

Methods	Independent variables	Distinctive characteristics	Applications
Log-linear regression	GDP, number of vehicles, population	An analysis of the relationship between independent variables ($X_1, X_2, \dots, X_n$) and dependent variable (Y) in logarithmic form	- Forecasting - Policy determination based on the relationship between independent variables and dependent variable
Path analysis	GDP, number of vehicles, population	An explanation of the direct and indirect influences of many independent variables on the dependent variable as well as directions and levels of relations among variables	- Forecasting - Policy determination based on the direct and indirect relationship between independent variables and dependent variable
Time series	Time period (years)	A study of movement or change in data during the given time period to estimate or predict the future data according to past data using forecasting techniques	Forecasting
Curve estimation	Time period (years)	A study of a change in the interesting data fitting with the available data in different functions, i.e., linear, logarithmic, inverse, quadratic, cubic, compound, power, S, growth, exponential, etc., considered as the numerical methods	Forecasting

In the efficiency evaluation of the models, the mean absolute percentage error was applied and calculated using the following formula:

$$MAPE = \frac{1}{n} \sum_{i=1}^n \left| \frac{F_i - O_i}{O_i} \right| \times 100 \quad (3)$$

where F_i is the forecast value from year i , and O_i is the actual value from year i .

4. Findings

4.1. Statistical analysis

4.1.1. Log-linear regression

According to the log-linear regression analysis, the development of four models was conducted in dissimilar forms; model 1 used CO_2 as a dependent variable, while independent variables

were the GDP, the number of small-sized registered vehicles, the number of medium-sized registered vehicles and the number of large-sized registered vehicles. For model 2, the same dependent variable as model 1 was considered, but the independent variables were changed to the total number of registered vehicles (no size separation) and the GDP. Models 3 and 4 involve the analysis of the amount of CO_2 per capita, with the variables from model 1 being analyzed in model 3. Model 4 used the parameters of model 2 and divided all of the variables in the model by the population.

The results from model development, presented in Table 3, found that in the model, only the number of large-sized registered vehicles remained in the equation, with a regression coefficient of 0.864 ($p=0.000$) and an adjusted R -square of 0.892; as a result, the change in the values of large-sized vehicle numbers can explain 89.2% of the change in the expected values of CO_2 emissions. In addition, a change in the other factors can be left out of the equation. Regarding model 2, the GDP exhibited a direct

Table 3

Log-linear regression model.

Variable	Model 1 (Y is CO_2)			Model 2 (Y is CO_2)		
	B	t-stat	p-Value	B	t-stat	p-Value
Ln(GDP)	–	–	–	0.846	11.805	0.000*
Ln(A_Veh)	–	–	–	–	–	–
Ln(S_Veh)	–	–	–	–	–	–
Ln(M_Veh)	–	–	–	–	–	–
Ln(L_Veh)	0.864	13.851	0.000*	–	–	–
Constant	4.132	150.886	0.000*	2.859	33.491	0.000*
F-test	191.846	–	–	139.357	–	–
Adjusted R^2	0.892	–	–	0.857	–	–
Variable	Model 3 (Y is CO_2 /population)			Model 4 (Y is CO_2 /population)		
	B	t-stat	p-Value	B	t-stat	p-Value
Ln(GDP/population)	–	–	–	0.806	8.744	0.000*
Ln(A_Veh/population)	–	–	–	–	–	–
Ln(S_Veh/population)	–	–	–	–	–	–
Ln(M_Veh/population)	–	–	–	–	–	–
Ln(L_Veh/population)	0.834	10.331	0.000*	–	–	–
Constant	3.438	9.515	0.000*	2.103	7.662	0.000*
F-test	106.737	–	–	76.456	–	–
Adjusted R^2	0.821	–	–	0.766	–	–

* Denotes significance at 0.01 level.

Table 4
Path analysis model

Relationship	Model statistics ^a			
	β	S.E.	t-stat	p-Value
Large vehicle $\rightarrow$ CO ₂	41.541	14.234	2.918	0.004*
GDP $\rightarrow$ CO ₂	2.607	2.962	0.880	0.379
Population $\rightarrow$ GDP	0.219	0.011	20.116	0.000*
Population $\rightarrow$ large vehicle	0.046	0.002	29.450	0.000*
Intercepts				
CO ₂	8.583	3.243	2.646	0.008*
GDP	-10.339	0.680	-15.211	0.000*
Large vehicle	-2.146	0.098	-21.872	0.000*
Residual variances				
CO ₂	14.549	4.200	3.464	0.001*
GDP	0.043	0.012	3.464	0.001*
Large vehicle	0.001	0.000	3.464	0.001*
R ²				
CO ₂	0.896	0.050	17.408	0.000
GDP	0.944	0.022	42.509	0.000
Large vehicle	0.973	0.011	89.735	0.000

^a Model is estimated by Mplus 7.11: $\chi^2=4.182$, $df=2$, $p=0.1235$, RMSEA=0.213, CFI=0.989, TLI=0.968, SRMR=0.005.

* Denotes significance at 0.01 level.

relationship with the change in the amount of CO₂ by representing the regression coefficient of 0.846 ($p=0.000$). This model can describe a change in GDP to CO₂ emissions of approximately 85.7% (adjusted $R^2=0.857$). For model 3, the study found that the number of large-sized registered vehicles per capita was directly associated with only one variable, namely a change in CO₂ emissions per capita, with a regression coefficient of 0.834 ($p=0.000$). In model 3, a change in the independent variables in the model due to the dependent variable explained 82.1% (adjusted $R^2=0.821$) of the variance. According to model 4, the GDP per capita exhibited a regression coefficient of 0.806 ($p=0.000$) and was found to be the only variable directly influencing a change in the amount of CO₂ per capita, with the model explaining 76.6% of the change (adjusted $R^2=0.766$). In addition, Models 1, 2, 3, and 4 exhibited *F*-test values equal to 191.846, 139.357, 106.737, and 76.456, respectively.

4.1.2. Path analysis

The results of model development based on path analysis via Mplus 7.11, as presented in Table 4, are as follows: chi-square=4.182, $df=2$, $p=0.1235$, chi-square/ $df=2.091$, RMSEA=0.213, CFI=0.989, TLI=0.968, and SRMR=0.005. When comparing the statistical value and the suggested value, the values of chi-square/ df should be less than 3 (Kline, 2005), Root Mean Square Error of Approximation (RMSEA) should be less than 0.07 (Steiger, 2007), the Comparative Fit Index (CFI) should equal to or more than 0.90 (Hu and Bentler, 1999), the Tucker–Lewis index (TLI) (also known as the Non-Normed Fit Index (NNFI)) should equal to or more than 0.80 (Hooper et al.,

2008), and the standardized root mean square residual (SRMR) should be less than 0.08 (Hu and Bentler, 1999); the findings indicated that the statistical values of all of the models fitted with the suggested values, except for RMSEA. Therefore, one can conclude that the structural equation model (SEM) of CO₂ emissions was consistent with the empirical data.

According to the model, CO₂ emissions have increased as a result of the significantly positive influences from the number of large-sized registered vehicles ($\beta=41.541$) at a significance level of 0.01 – considered as the most influential. Additionally, the number of large-sized registered vehicles was significantly positively affected by of the population ($\beta=0.046$), followed by GDP ($\beta=2.607$) at a significance level of 0.01. Simultaneously, the model demonstrated the significant positive relationship between GDP and population ($\beta=0.219$) at a significance level of 0.01 as well, thus clarifying the relationship between the independent variables and the dependent variable at 89.6% ($R^2=0.896$).

4.1.3. Time series

In the analysis of the time series performed to predict the amount of CO₂ released from the transportation sector, the study applied SPSS 16.0 with the expert modeler and found that the best-fitting model was ARIMA (0, 1, 0). The ARIMA model exhibited values of R^2 of 0.871, root mean square error of 3.534, and mean absolute percentage error of 5.388.

4.1.4. Curve estimation

For the CO₂ emissions estimation via the curve estimation technique, SPSS 16.0 was used in the analysis, in a manner similar to the log-linear and the time series techniques. The analysis results, presented in Table 5, contained 10 models: linear, logarithmic, inverse, quadratic, cubic, compound, power, S, growth, and exponential. The study found that the model with the maximum R-square value was the cubic model ($Y_t=16.727+6.118t-0.372t^2+0.008t^3$), with a value of 0.894, followed by the power model ($Y_t=23.719t^{0.295}$), with a value of 0.892, and the logarithmic ($Y_t=20.329+12.329 \ln(t)$) model, with a value of 0.867.

4.2. Model testing

According to the evaluation of the efficiencies of 7 models (based on Eq. (3)), the study found that the time series (ARIMA) exhibited the minimum MAPE with 5.388%, followed by log-linear1, log-linear3, curve estimation (cubic), log-linear4, log-linear2, and path analysis with values of MAPE of 6.379, 6.474, 6.617, 8.146, 8.169, and 16.335, as presented in Table 6.

4.3. CO₂ forecasting

A forecast of CO₂ amounts requires the use of the projection data of 3 independent variables, namely GDP, population, and

Table 5
Curve fit models.

Model	R ²	Adjusted R ²	Std. error of the est.	F	Equation
Linear	0.782	0.772	5.131	78.943	$E(y)_t=14.358+8.885T$
Logarithmic	0.867	0.861	4.001	144.003	$E(y)_t=20.329+12.329 \ln(T)$
Inverse	0.619	0.602	6.781	35.811	$E(y)_t=54.202+(-40.374/T)$
Quadratic	0.854	0.840	4.296	61.519	$E(y)_t=23.880+2.998T-0.066T^2$
Cubic	0.894	0.878	3.750	56.330	$E(y)_t=16.727+6.118T-0.372T^2+0.008T^3$
Compound	0.739	0.727	0.137	62.164	$E(y)_t=31.350(1.032)^T$
Power	0.892	0.887	0.087	181.223	$E(y)_t=23.719T^{0.295}$
S	0.697	0.684	0.146	50.677	$E(y)_t=\exp[4.001+(-1.033/T)]$
Growth	0.739	0.727	0.135	62.164	$E(y)_t=\exp(3.445+0.031T)$
Exponential	0.739	0.727	0.135	62.164	$E(y)_t=31.350 \exp^{0.0317}$

Table 6
Comparison of the absolute percentage error for the different methods.

Year	Log-linear (model 1)	Log-linear (model 2)	Log-linear (model 3)	Log-linear (model 4)	Path analysis	Time series (ARIMA)	Curve fit (cubic)
1990	4.297	8.089	4.255	7.842	17.382	7.247	2.876
1995	16.033	9.855	16.120	10.466	30.089	11.388	8.591
2000	9.065	2.784	9.020	2.653	10.820	7.406	10.622
2010	4.149	10.079	4.783	10.036	8.750	2.166	1.959
MAPE*	6.379	8.169	6.474	8.146	16.335	5.388	6.617

* Average MAPE from 1989 to 2012.

Table 7
Projection of the independent variables.

Year	GDP (10 ¹² baht) 1998 constant price	Population (10 ⁶)	Vehicles registered (10 ⁶ vehicles), large
2015	5.53	65.77	1.05
2020	6.79	66.54	1.20
2025	8.29	67.37	1.37
2030	10.02	67.34	1.58

Source: Limanond et al. (2011).

number of large-sized registered vehicles, as the input data into the log-linear and path analysis models. Such data were reported in the study of Limanond et al. (2011), as listed in Table 7. The data indicated the growth of GDP, population, and large-sized registered vehicle numbers from 2012 to 2030 with increases of 104.6, 4.4, and 51.9, respectively.

Concerning the CO₂ emissions forecast, researchers conducted predictions of CO₂ concentration for 2030, the results of which are presented in Table 8 and Fig. 8 for 7 models. For 2030, from the CO₂ forecast according to each model, the log-linear model 1 predicted that the CO₂ emitted from the transportation sector is equivalent to 92.50 million tons, which significantly relied on the number of large-sized registered vehicles; however, the economic growth influenced the forecasted amount of CO₂ in log-linear model 2, which was equal to 122.57 million tons. When adding the population size into the models, the study found CO₂ levels in the log-linear models 2 and 3, with 91.68 and 118.77 million tons, respectively. Along with the path analysis, both the number of large-sized registered vehicles and the GDP increased the CO₂ concentrations with the predicted values of 100.34 million tons. Considering the time series and curve estimation models and using the trends of CO₂ released from 1989–2012 (24 years), the models predicted CO₂ concentrations in 2030 equal to 135.98 and 225.33 million tons, respectively.

Examination of the forecast results of the 7 models indicated that the maximum CO₂ levels were provided in the curve estimation (cubic) model, followed by the time series model (ARIMA), while log-linear model 3 provided the minimum CO₂ value. The

Table 8
Comparison of the projected CO₂ emissions from the transportation sector (10⁶ t) for the different methods.

Year	Log-linear (model 1)	Log-linear (model 2)	Log-linear (model 3)	Log-linear (model 4)	Path analysis	Time series (ARIMA)	Curve fit (cubic)
2015	64.98	74.13	64.95	73.22	66.62	71.76	72.26
2020	72.93	88.19	72.74	86.59	76.13	88.80	100.46
2025	81.78	104.41	81.41	101.95	87.11	109.88	149.43
2030	92.50	122.57	91.68	118.77	100.34	135.98	225.33

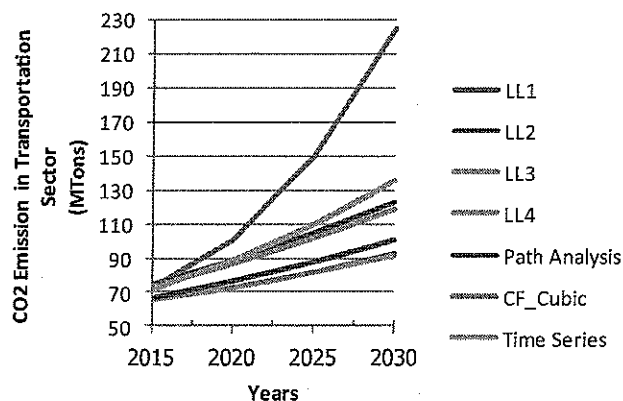


Fig. 8. A comparison of the forecasting results.

increased CO₂ rates since 2012 of the curve estimation, time series, and log-linear models were found to be 257%, 115%, and 45%, respectively.

5. Policy Mitigation in Thailand

To reduce CO₂ emissions in Thailand, the Ministry of Energy proposed three main strategies for energy conservation in the transportation sector, including (1) improvement of the energy efficiency of vehicles, (2) enhancement of the energy efficiency via a modal shift of passenger and freight transportation, and (3) increase of efficient energy consumption through travel demand management (TDM) (Ministry of Energy, 2011), which can be described as follows.

- 1) *Improving the energy efficiency of vehicles* by considering the current vehicle fuel economy and the improved fuel economy in the future, with a target of a 20% improvement in 2030. In addition, for motorcycles, evaluate the potential for the energy efficiency of motorcycles by increasing the proportion of the use of electric motorcycles to motorcycles powered by internal combustion engines.
- 2) *Enhancing energy use efficiency via modal shift of freight transportation*: Currently, road freight transportation is the primary form used across Thailand and seems to have the greatest rate of energy use per transportation unit when compared to the other transportation patterns. The report also revealed that the use of truck transportation consumed 10 times more fuel than rail transit.
- 3) *Increasing efficient energy consumption through travel demand management (TDM)*, which includes (1) a group of support measures for a variety of trip patterns with higher vehicle occupancy rates, (2) a group of incentive or disincentive measures for trip reduction, and (3) a group of measures for enhancing mobility options and travel choices, particularly those measures related to managing high rates of vehicle occupancy or low rates of energy use per transportation unit, e.g., a park-and-ride management system in suburban areas, improving the connection between public transportation and other transit systems, and reducing public transportation fees for off-peak hours.

In addition, the Office of Traffic and Transport Policy and Planning (OTP) has developed a Master Plan for an Environmentally Sustainable Transport System, which proposes six strategies including (1) upgrade the capability of agencies and personnel for the development of an environmentally sustainable

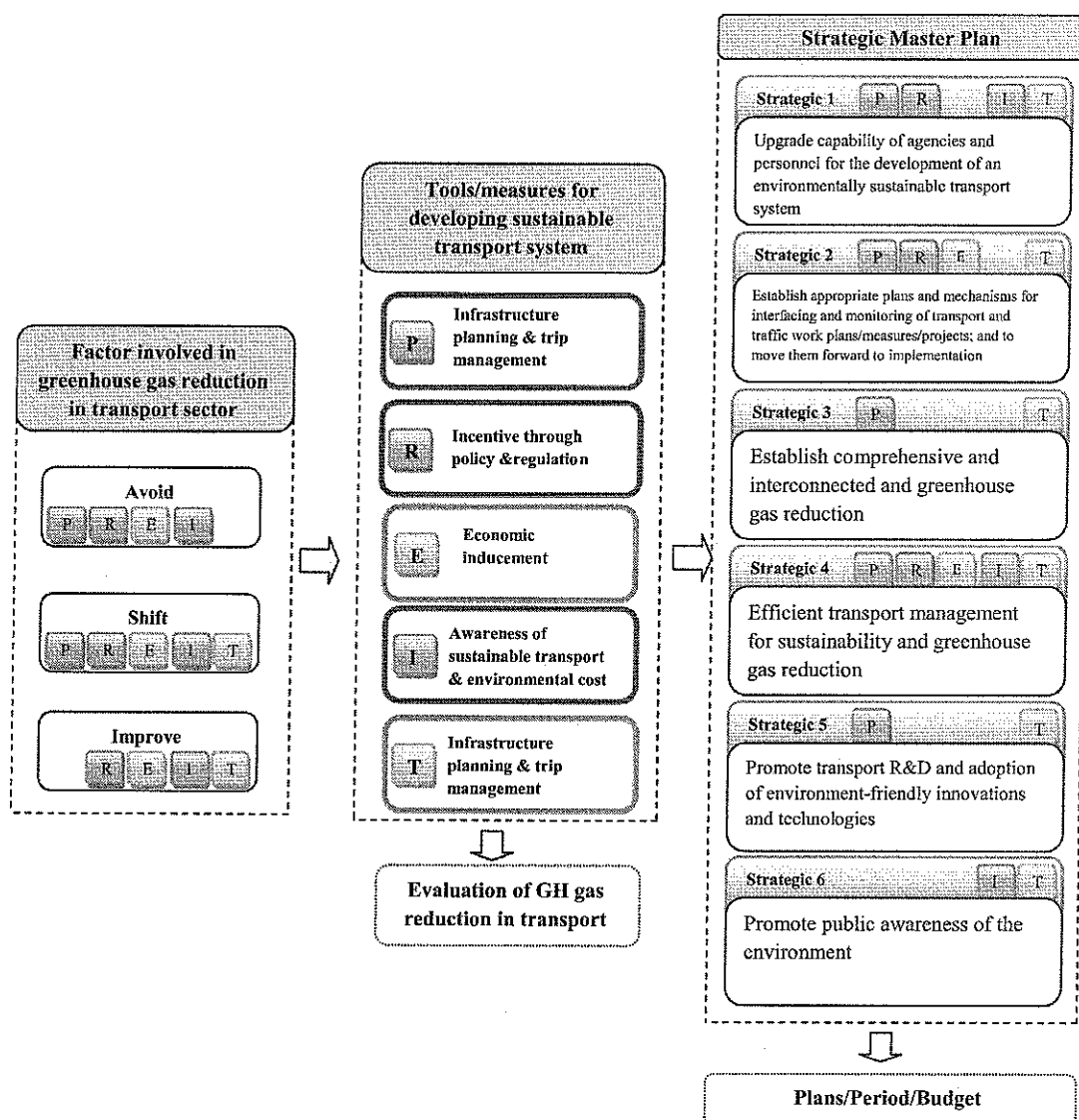


Fig. 9. Relationship of shift-avoid-improve, 5 instruments and 6 strategies of the Master Plan (The Office of Traffic and Transport Policy and Planning, 2012).

transportation system; (2) establish appropriate plans and mechanisms for the interfacing and monitoring of transportation and traffic work plans/measures/projects and to move them forward to implementation; (3) establish a comprehensive and interconnected transportation infrastructure; (4) implement efficient transportation management for sustainability and greenhouse gas reduction; (5) promote transportation R&D and adoption of environmentally friendly innovations and technologies; and (6) promote public awareness of the environment. The Plan has adopted a new paradigm of enhancing sustainable transportation development to reduce energy consumption and GHG emissions from the transportation sector, called the avoid-shift-improve approach, which provides guidance toward a more sustainable transportation system. In this regard, the major instruments or measures used as a framework include the following: Planning Instrument (P), Regulatory Instrument (R), Economic Instrument (E), Information Instrument (I), and Technology Instrument (T). The relationship of this approach is illustrated in Fig. 9. According to an analysis of the potential of the Plan, the top five projects having a significantly high potential of GHG emissions reduction for inter-urban transportation are: collection of transportation fees

according to the distance traveled (5–7%), establishment of standards on fuel consumption in modern cars (3–5%), plan/project to dispose of old cars (2–4%), speed limit on highways and motorways (2–4%), and plan/project to minimize empty journeys of trucks (2–4%). The top five projects representing the potential of GHG emissions reduction for travel within Bangkok and its vicinity are: collection of transportation fees according to the distance traveled (8–11%), reforms of bus operations (bus lanes, ITS and Smart Card, central administration center and quality improvement) (4.5–7.5%), electric trains for mass transportation systems (5.8%), establishment of standards on fuel consumption in modern cars (3–5%), and plan/project to promote the use of environmentally friendly cars (hybrid, electric or fuel cell) (1.5–3.5%). In this case, the numbers in parentheses are the values of GHG emission reduction potential (The Office of Traffic and Transport Policy and Planning, 2012). However, an example of an interesting project related to this concern in Thailand is the free bus project. The project focuses on changing the behaviors of people from private car use to public transportation use, which is recognized as a primary policy approach for reducing GHG emissions. Regarding this project, the Thailand Government has announced a policy of

free bus services in Bangkok – the capital city of Thailand since August 1, 2008, to present (August 20, 2014) – including 800 buses within 85 routes. Moreover, the Government has also provided free interurban rail services in the form of 164 Public Service Obligation Trains for all of the routes, together with 8 Commercial Trains (free only for the third-class service).

When considering the aforementioned strategies together with the results from this article, the direct relationship between the number of large-sized vehicles and the levels of CO₂ emissions is clearly exemplified in relation to strategy 2 of the Ministry of Energy and strategy 2 of OTP (under the SRT's rail infrastructure policies on MRT development and its freight transportation service), i.e., a modal shift in transportation of cargo to the rail system is recommended in Thailand because truck transportation is commonly used for long-distance domestic freight services, with up to 86% of the freight transported via trucks (Limanond et al., 2011). Yet, the execution of such a strategy tends to require large budgets and long time periods; as a result, long-term strategies are required for this case. However, some short-term policies and practices can be implemented: (1) a suitable trucking logistics management system, such as reduction of the overall empty return trips of truck freight (which result in low fuel efficiency) by means of milk-run logistics; (2) truck fuel economy improvement; and (3) the use of alternative fuels that release lower amounts of CO₂ than the traditional truck fuels.

6. Discussion and conclusion

Because the trends of energy consumption in the transportation sector continue to increase yearly, significant levels of CO₂ emissions exist. Hence, the intention of this study was to find the factors influencing the increase in CO₂ concentrations that involve the population, GDP, and the numbers of small-, medium- and large-sized registered vehicles by analyzing the 1989–2012 data using two statistical methods, namely log-linear regression and path analysis. The main conclusions based on the results are as follows:

- i. Regarding the analysis of the log-linear regression, the only influential factor directly associated with CO₂ levels in model 1 was the number of large-sized vehicles (from 4 independent variables, i.e., GDP and numbers of small-, medium- and large-sized vehicles). For model 3, which analyzes the amount of CO₂ per capita, the same significant factor, the number of large-sized vehicles, was found to provide evidence of the large amount of truck-freight shipping in Thailand, which significantly affects the increase in energy consumption and CO₂ emissions.
- ii. From the analysis of log-linear regression model 2, GDP was found to exhibit a direct correlation with the increase in CO₂ levels (when considering 2 independent variables, including GDP and the total number of registered vehicles). In addition, this factor was confirmed in model 4 in which the amount of CO₂ per capita was brought into the analysis, similar to Thailand's case studies of Limanond et al. (2011), Chandran and Tang (2013), and Saboori and Sulaiman (2013).
- iii. Based on the overall analysis of the 4 log-linear regression models when changing the independent or input variables from the number of registered vehicles with size separation (small-, medium- and large-sized registered vehicles) to the total number of registered vehicles while keeping a GDP variable in the model, a different significant independent variable was found; the results revealed that only the number of large-sized registered vehicles remained in models 1 and 3, while models 2 and 4 had GDP as a significant parameter. This result

was possibly due to the relationship between GDP and the number of large-sized registered vehicles.

- iv. According to the path analysis, an increase in CO₂ was found due to the direct and positive influences of the number of large-sized registered vehicles at a significance level of 0.01, along with the indirect effects of the population growth transferred to the larger number of large-sized vehicles, as was similarly found in the study of de Freitas and Kaneko (2011), which indicated the relationship between the impacts of CO₂ levels and the population expansion.

Regarding the forecast of CO₂ levels in this study, 4 statistical methods were applied. Time series and curve estimation were identified as the techniques to use for data trends not relying on other variables to compare the results from the log-linear and the path analysis approaches. Of the predicted results specified in 2030, the curve estimation (cubic) produced the maximum CO₂ concentration of 225.33 million tons, and the time series produced the minimum mean absolute percent error (MAPE=5.388), with the forecasted CO₂ amount of 135.88 million tons.

From the forecast results according to the model with the minimum MAPE, the rate of increase in CO₂ emissions from 2012 to 2030 reached 115%. To reduce the impacts of larger CO₂ concentrations, policy intervention is required for the transportation sector, such as improving truck fuel efficiency or enhancing the modal shift of freight transportation patterns from truck to rail. According to the study of Ramanathan and Parikh (1999), a change in freight patterns to a public transit system can reduce energy consumption by up to 45%; in addition, an increase in energy efficiency would enable a fuel use reduction of 16%.

However, the selection of the forecast method greatly depended on the available data used for analysis – whether considering the methods applied in this study (log-linear regression, path analysis, time series, curve estimation) or in previous studies in Thailand (Artificial neural network (Limanond et al., 2011), LEAP (Eau-Arpon et al., 2008)) because each method has its own strengths and weaknesses. According to the aforementioned results, when the CO₂ concentrations in the transportation sector in the future are forecasted, the related agencies in Thailand, such as the Ministry of Transport and the Ministry of Energy, can use such results as a guide for implementing practices through the preparation of Nationally Appropriate Mitigation Actions (NAMAs) for the transportation sector. In this respect, a policy evaluation should be performed to identify whether such policies provide the efficiency of impact mitigation required to respond to the increase in CO₂ amounts.

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