Possibility to Realize Low Carbon City in Medium-sized City of Asia: Case Study in Khon Kaen City, Thailand

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Abstract: The shift to a Low Carbon Society is required for dealing with global warming. However, it is not clear how much CO_2 emissions by introduction of integrated transportation and land use policies will be decreased in medium-sized cities of Asia. Therefore, in this study, CO_2 emissions were estimated based on some forecast scenarios by applying some those policies such as TOD (Transit Oriented Development), introduction of BRT (Bus Rapid Transit) using ethanol buses (EB), conversion from fossil fuel powered vehicles to electric vehicles (EV), and hybrid vehicles (HV) in Khon Kaen City, Thailand. In conclusion, the reduction of CO_2 emissions of up to approximately 48% as compared to BAU (Business As Usual) scenario was indicated by introducing those policies in Khon Kaen city, Thailand.

Keywords: Transit Oriented Development, BRT, CO_2 Emissions, Low Carbon Society, Diffusion of EV and HV

1. INTRODUCTION

In recent years, the shift to a Low Carbon Society is considered as a solution to the global warming problem. Particularly, automobiles have spread rapidly through many cities of the developing countries and this trend is assumed to continue in the future. Thus, it’s important to carry out comprehensive policies by considering land use together with introduction of low carbon public transportation in the early stages of city planning. But, CO_2 reduction carrying out these kinds of policies are not in effect.

Therefore, this study, targets Khon Kaen city, Thailand with planning from Songthaew to BRT. Purpose of this study is to clarify the effects of introducing comprehensive policy by estimation of CO_2 reduction when considering introduction of BRT using Ethanol Buses, TOD, and conversion from fossil fuel powered vehicles to electric vehicles, and hybrid vehicles.

2. LITERATURE REVIEWS

There are several studies which evaluate the effect of CO_2 reduction by introducing transportation policy and/or land use policy. However, comprehensive policies in which several policies are combined with various aspects considering hierarchy and complexity have never been evaluated under the integrated methodology, although individual policies has been dealt with under the different methodology in each study.

Regarding TOD policies, many researchers tried to evaluate CO_2 emission reduction by introducing TOD policies. For example, Min, et al. (2007) compared the CO_2 emission reductions applying TOD policies or AOD (Auto Oriented Development) in Dongguan city, China. AOD means that non-strict land use policies to aggregate land use along transit corridors are passenger car based transportation assumed to be mainly used in the city. In the study, they assumed several scenarios in which land use policies are set to allocate high density residence areas around five hundred kilometers from station of public transit. The CO_2 emission and energy consumption under the both TOD and AOD scenarios were estimated. It was concluded that the CO_2 emission was reduced more in the case of TOD than AOD, and the vehicle kilometer of traveled also was decreased.

In order to develop methodology to evaluate land use policy and public transit simultaneously, several studies tried to employ bi-level traffic demand model. Bi-level traffic demand model consists of upper model and lower model: upper model is to calculate maximum possible trips subjecting to the environmental capacities, lower model employs the general equilibrium assignment model integrating modal choice and origin-distribution model to express suitable economic activities and transport under the output of upper model. The lowly model is one of the most famous of bi-level models. There are many studies to evaluate the possibility of CO_2 emission reduction in using the bi-level models. For example, Gojash, et al. (2007) estimated the maximum possible trips applying an emission constant in the case of Chengdu, China. These results depend on road networks and public transportation in each targeted study area. Therefore, the estimated value cannot be compared across different cities. Introducing as one representative study, Gojash, et al. estimated an increase of 2% possible trips under the introduction of one subway line in Chengdu, China. However, in employing bi-level model, it is difficult to verify trends and effects of each of the policies and their combination because the bi-level model provides only one result under the subject. And all of existing studies have never evaluated technological innovation, such as HV and EV diffusion.

On the other hand, traffic demand forecasting model generally may not include logistic cargo (Truck) OD flow because of lack of actual data of OD table for freight movement in medium-sized city of Asia counties. To deal with freight movement, Kaneko, et al. (2005) considers the multi-mode user equilibrium model for evaluating emission in Bangkok. However, current technological innovations such as HV and EV were not concerned.

Finally, there are some studies to use heuristic policy analysis to clarify effects of each policy. For example, Rodiera, et al. (2002) estimated that the potential emission reduction is 5-7% in introducing transit policies in Sacramento, California, USA. This study did not include TOD policy or technological innovation.

In the present study, we focus on the effect of CO_2 reduction under the combination of several policies such as TOD policy, public transit policy, technological innovation, and freight traffic. This study might provide some important outcomes for the medium-sized cities of Asia counties.

3. OVERVIEW IN KHON KAEN CITY

3.1 Current Traffic Situation

In Khon Kaen city, Thailand, the number of motor vehicle registrations had increased at approximately 12% each year in the 1990's. As a result, the motorization and urban sprawl according to economic growth has posed many problems such as traffic congestion and environmental issues, therefore the modal share of private automobiles has been increasing.

Although there was a plan to introduce local buses previously, now there are few local buses due to the failing introduction of local buses. At present, 751 Songthaews converted from trucks run in Khon Kaen city as the main public transportation.

3.2 Plan of BRT

The plan is to introduce 5 BRT lines in the center of the city, forged by Khon Kaen city between 2007 and 2022 (Figure.1). In the first five years, main 3 BRT lines (Red Line, Blue Line and Pink Line) will be constructed with 63 buses, and then 2 BRT lines (Green Line and Yellow Line) will be built with 49 buses in the next decade. Some pilot programs like lane restrictions are carried out, but there has been a delay in the construction of each BRT line.

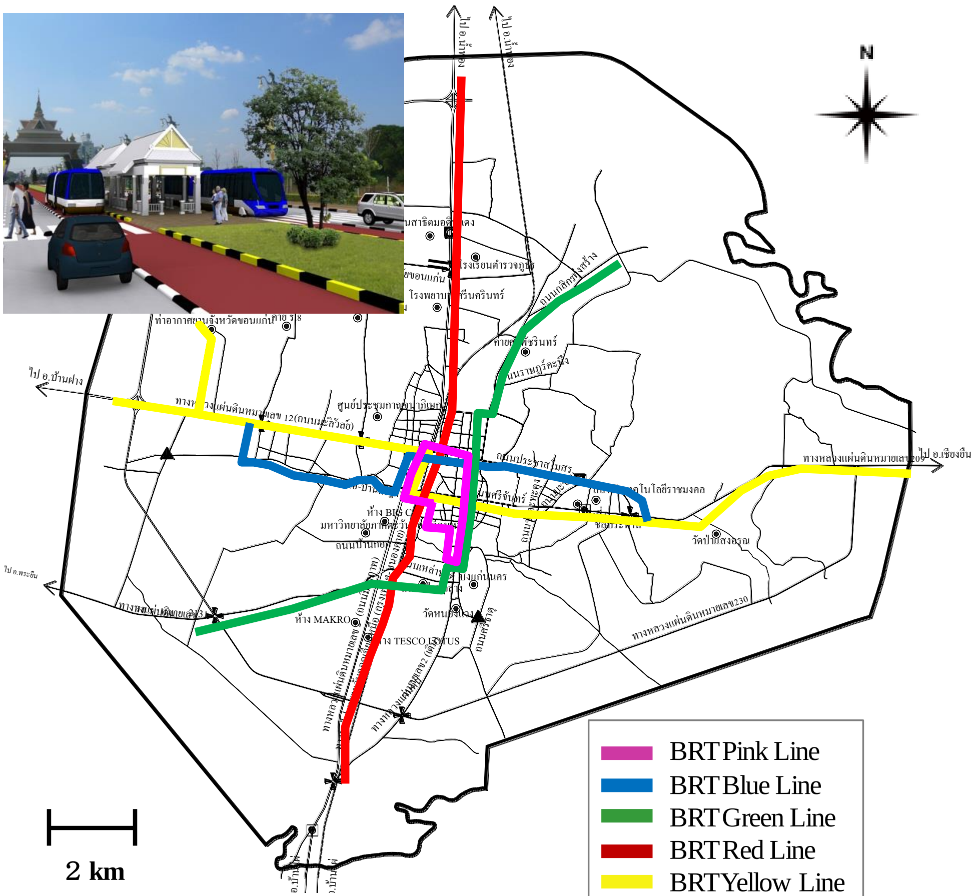

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Figure 1. BRT plans in Khon Kaen city and image of BRT

3.3 Necessity of introducing TOD in Khon Kaen

The population of the entire Khon Kaen city is approximately 3.8 hundred thousand, and the population in the center of the city is approximately 1.2 hundred thousand. The population growth rate of the entire city is 0.203% in the three years between 2004 and 2007, but the population growth rate in the center of the city (Nai Mueang district) is -0.814%. Thus, while the population of the city is increasing, in the center of the city it is decreasing due to the suburban sprawl.

In recent years, a high concentration of cars and motorcycles in the center of the city causes chronic traffic congestion during commuter rush hours because the housing land development is sprawling into suburban areas. Even if BRT lines were introduced under the current situation, the modal shift from cars and motorcycles to BRT lines is not expected without effective land use policy such as TOD policy. Figure 2 shows the future image of population density in the whole Khon Kaen city introduced TOD policy in 2030. This image was estimated for this study based on the concept proposed by Calthorpe (1993).

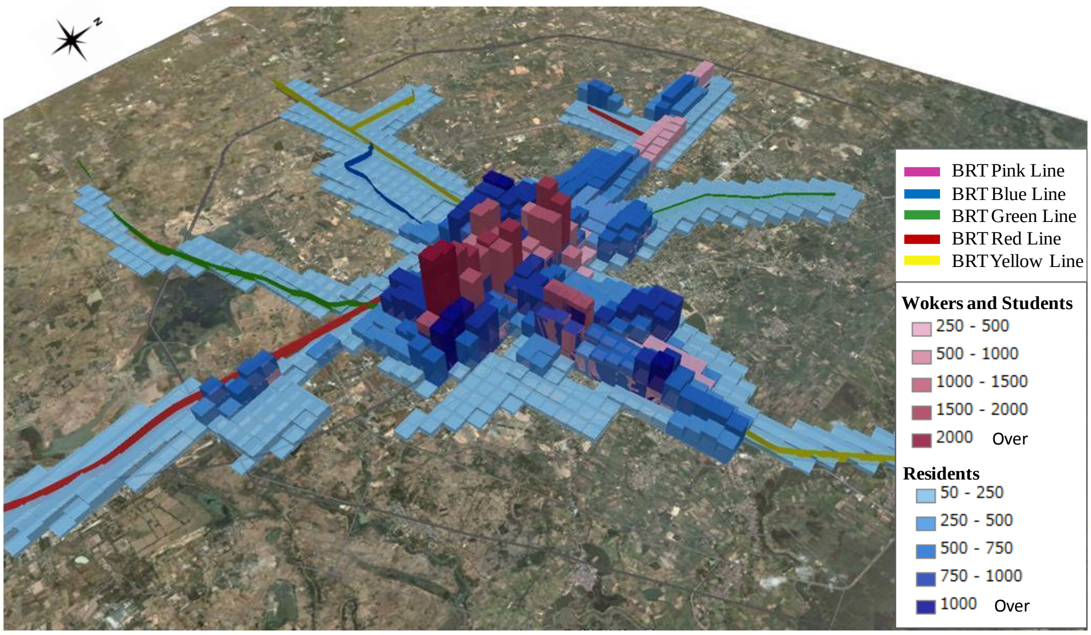

Figure 2. Future image of population density with TOD in 2030

4. METHODOLOGY

4.1 Outline of Methodology

The overall structure of the methodology to evaluate CO_2 emission reduction by introduction of integrated transportation and land use is shown in Figure 3. The methodology consists of five steps: estimating the future OD matrix, setting scenarios, estimating the traffic volume, analyzing results, and estimating CO_2 emissions. The scenario is set to consider the potential strategies which would contribute to reducing CO_2 emissions. For verifying the impact of introducing BRT lines in Khon Kaen, a combined model with traffic assignment and modal split is employed. Based on the result of the traffic assignment, CO_2 emissions are estimated by using the CO_2 emission factors developed by several institutions considering the current traffic situation in Thailand.

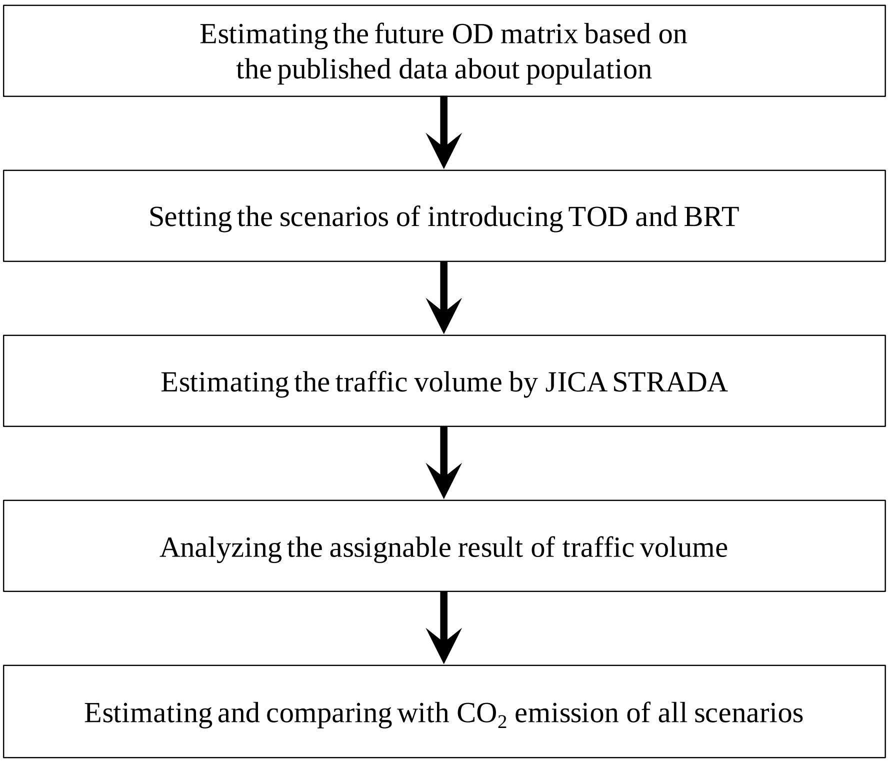

Figure 3. Flow of evaluation

4.2 Scenario Setting

The some factors described in section 3 of this paper are cross setting, as shown in Figure 3. The future OD matrix in 2030 in Business As Usual (BAU) is estimated based on the published data about population and its density in Khon Kaen city. The estimation on all scenarios used the future OD matrix on BAU. The OD matrix under introduction of TOD is calculated in assumption of generated trip converted from all zones to the zones along BRT lines. For this study, three TOD scenarios were set, A: 10%, B: 30%, and C: 50%. This is supposed that reproducing the situation of movement of the people to along BRT lines.

It is assumed that all BRT lines are constructed in 2030. In the case with BRT, the existing Songthaew route is discontinued and all passenger of Songthaew is assumed to be shifted to BRT. The technological innovation for vehicles with engines would have occurred and EV/HV would be used more in near future. Therefore the conversation rate to EV/HV from fossil fuel powered vehicles is considered: 0%, 30% and 50%. Based on trend of EV/HV in Thailand, Truck and motorcycle would convert to EV and passenger car would convert to HV. The conversion rate is set with reference of the advanced vehicle strategies 2010, Ministry of Economy, Trade and Industry of Japan. The reason why these numerical values were used is because this kind of detailed research does not exist clearly for Japan or Thailand.

On Scenario 1, the Songthaews are assumed to be main public transportation without the introduction of BRT, and there is a shifting from fossil fuel powered vehicles, and fossil fuel powered freight vehicles to hybrid vehicles, electric motorcycles, and electric freight vehicles. Scenario 2 is assumed only introduction of BRT. Scenario 3 is assumed the introduction of BRT along with a shifting from fossil fuel powered vehicles to hybrid vehicles, and electric motorcycles. Scenario 4 is assumed the introduction of BRT and a shifting from fossil fuel powered freight vehicles to electric freight vehicles. Scenario 5 is assumed the introduction of BRT and shifting from fossil fuel powered vehicles and fossil fuel powered freight vehicles to electric freight vehicles and hybrid vehicles. Scenario 6 is assumed the introduction of BRT and a shifting from fossil fuel powered vehicles and fossil fuel powered freight vehicles to hybrid vehicles, electric motorcycles, and electric freight vehicles.

4.3 Demand Forecasting Model

Demand forecasting model was used for estimating the CO_2 emissions under some scenarios related to transportation and land use policies. In addition, the integrated modal choice and assignment model, which can estimate the traffic volume of modal choice and traffic assignment in parallel, was utilized for calculating the CO_2 emissions.

The combined modal split and assignment model is employed to consider BRT introduction. In this study, the JICA STRADA, which is one of software for transport demand forecasting, making OD matrix and the road network, was utilized. The changes in the users of automobile traffic and public traffic are theoretically split by using a nested logit model and the choices over means of travel and paths. The combined model is solved by satisfying the requirements of network equilibrium expressed by the following mathematical optimization equations.

$$\begin{aligned} \min .Z(x(f),q,O) &= \sum_{m}\sum_{a}\int_{0}^{x_a^m} t_a^m(\omega)d\omega \\ &+ \sum_{rs}\sum_{m}\sum_{p}\sum_{k}\frac{1}{\theta_1^p} f_{m,k}^{rs,p}\ln\left(f_{m,k}^{rs,p}/q_m^{rs,p}\right) \\ &+ \sum_{rs}\sum_{m}\sum_{p}\frac{1}{\theta_2^p} q_m^{rs,p}\ln\left(q_m^{rs,p}/q^{rs,p}\right) \\ &+ \sum_{rs}\sum_{m}\sum_{p} q_m^{rs,p} C_m^{rs,p} \end{aligned} \tag{1}$$

where,

$f_{m,k}^{rs,p}$: traffic volume of purpose *p* and mode *m* on route *k* for OD pare between zone *r* and *s*

$q_m^{rs,p}$: OD trip of purpose *p* and mode *m* for OD pare between zone *r* and *s*

$q^{rs,p}$: OD trip of purpose *p* for OD pare between zone *r* and *s*

$C_m^{rs,p}$: travel cost of purpose *p* and mode for OD pare between zone *r* and *s*

When the optimization problem is solved, generally simplicity decomposition method or the partial linear approximation method may be applied. The JICA STRADA Model uses the simplicity decomposition method.

On the other hand, to consider actual traffic situation in Thailand, the parameter estimated by Sittha, et al. (2009) in Bangkok was used, as in the following equation.

$$c_a^{auto}(V_a^{auto}) = t_a^0\left(1+0.73\left(\frac{V_a^{auto}}{C_a}\right)^3\right) \tag{2}$$

where,

t_a^0 : free flow travel time (in minute) of link *a*,

V_a^{auto} : hourly volume of autos on the link *a*,

C_a : capacity of link *a* in veh/hr.

To verify the accuracy of the demand forecast model a correlation analysis has been carried out. The data used for this analysis was taken from results of the traffic assignment. The result, the estimated freight transportation value, was then compared with the observed freight transportation volume of Khon Kaen City. As shown in figure 4 the estimated values of the model are very close to the observed once, which supports the accuracy of the model.

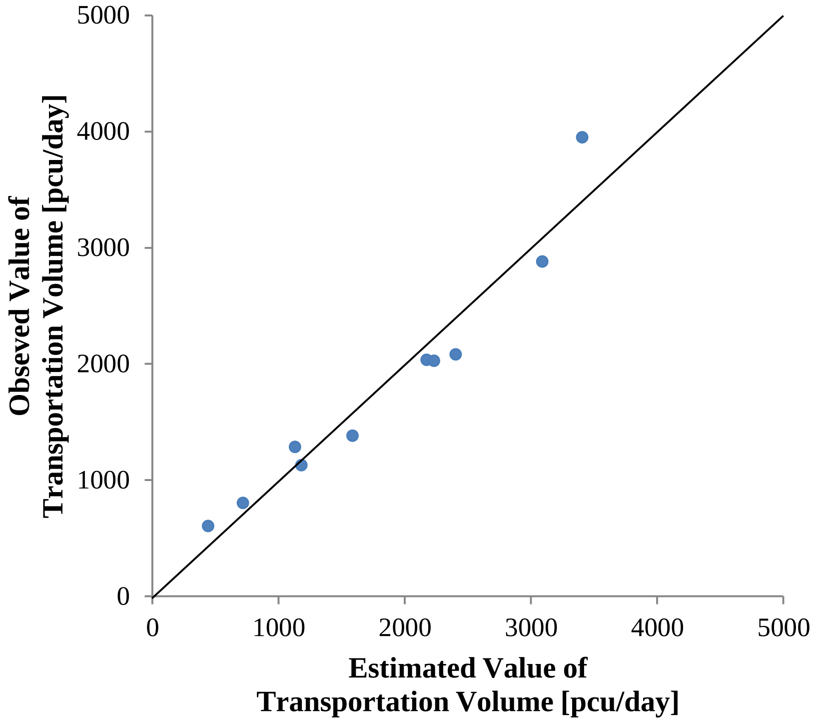

Figure 4. Correlation analysis of observed and estimated Value of freight transportation volume

4.4 Estimation of CO_2 emission and Emission Factor

The CO_2 emission factor is important to verify CO_2 emission reduction. To express reliable CO_2 emission under actual traffic situation, the emission factor refers the report "Project of Clean Developing Mechanism for Solution of Global Warming Problems" by MLIT, JAPAN, was used. In the report, the emission factor was estimated on the chassis dynamo meter test running typical running pattern in Bangkok. The emission factor of passenger cars and buses has a high accuracy. However, ethanol emission factors of buses, EV and HV have not been estimated in this report. Therefore, the emission factors for these vehicles were assumed based on many previous technical papers and the value of NISSAN "LEAF."

The equation to calculate CO_2 emissions is formulated as follow:

$$E = \sum_{m \in M} \sum_{r \in R} \sum_{s \in S} q_{rs}^{m} l_{rs}^{m} EF_{rs}^{m} \tag{3}$$

$$EF_{rs}^{m} = \left(a^{m} V_{rs,m}^{2} + b^{m} V_{rs,m} + c^{m} \right) \tag{4}$$

where,

$m \in M$: m is the set M of available mode between OD pare between zone r and s,
$r \in R$: r is the member of the set R of origin,
$s \in S$: s is the member of the set S of destination,
q_{rs}^{m} : trip distribution by mode between zone r and s,
l_{rs}^{m} : the shortest distance by mode between zone r and m,
EF_{rs}^{m} : emission factor of CO_2 by vehicle type,
$V_{rs,m}$: average speed by vehicle type between zone r and s,
a^m, b^m, c^m: parameters of emission factor by vehicle type.

5. RESULTS

As a result, it was indicated that the C-6 scenario could reduce CO_2 emission maximumly scenario. It assumes introducing TOD and BRT with shifting to electric freight vehicles, hybrid vehicles, and electric motorcycles were giving the biggest reduction rate (48.2%) of CO_2 emissions among all scenarios.

In comparison with scenario 1 and 6 over A, B and C, the effect of introducing BRT is about 10%. And then if TOD policy was introduced, CO_2 was reduced about 10% in scenario A, about 20% in scenario B, and about 30% in scenario C in comparison with BAU.

Regarding technological innovation, as mentioned conversion rate from fossil fuel powered vehicles to EV and HV, the effect of converting freight trucks to EV is about 5%, as shown in scenario 1 and scenario 4. Scenario 5 adds the conversion of passenger cars to HV and compared with scenario 4 it has the effect of about 5% over scenario A, B and C. Finally, if motorcycles are converted to EV from fossil fuel powered vehicles, a small reduction rate was shown of about 1 or 2%, in comparison scenario 5.

Figure 5 shows the CO_2 emissions of each modal type in all scenarios. Consequently, even the TOD policies and the ratio of shifting to hybrid cars and electric vehicles are differences, the modal share tends not to be much different in all scenarios.

Table 1. Results of the amount of CO_2 emissions in all scenarios

Scenarios		TOD[%]	Introduction of BRT (EB)	Conversion ratio to Freight(EV)[%]	Conversion ratio to PC(HV)[%]	Conversion ratio to MC(EV)[%]	CO_2 Emission [t-CO_2/year]	Amount of change from BAU[t-CO_2/year]	Rate of change from BAU[%]
BAU		0		0	0	0	96,829	—	—
A	1	10		50	30	30	78,037	-18792.4	-19.4
	2		✓	0	0	0	86,434	-10395.4	-10.7
	3		✓	0	30	30	75,814	-21015.4	-21.7
	4		✓	50	0	0	80,334	-16495.4	-17.0
	5		✓	50	30	0	71,035	-25794.4	-26.6
	6		✓	50	30	30	69,713	-27116.4	-28.0
B	1	30		50	30	30	68,450	-28379.4	-29.3
	2		✓	0	0	0	73,964	-22865.4	-23.6
	3		✓	0	30	30	63,554	-33275.4	-34.4
	4		✓	50	0	0	68,936	-27893.4	-28.8
	5		✓	50	30	0	59,799	-37030.4	-38.2
	6		✓	50	30	30	58,525	-38304.4	-39.6
C	1	50		50	30	30	63,467	-33362.4	-34.5
	2		✓	0	0	0	65,464	-31365.4	-32.4
	3		✓	0	30	30	55,140	-41689.4	-43.1
	4		✓	50	0	0	60,512	-36317.4	-37.5
	5		✓	50	30	0	51,429	-45400.4	-46.9
	6		✓	50	30	30	50,187	-46642.4	-48.2

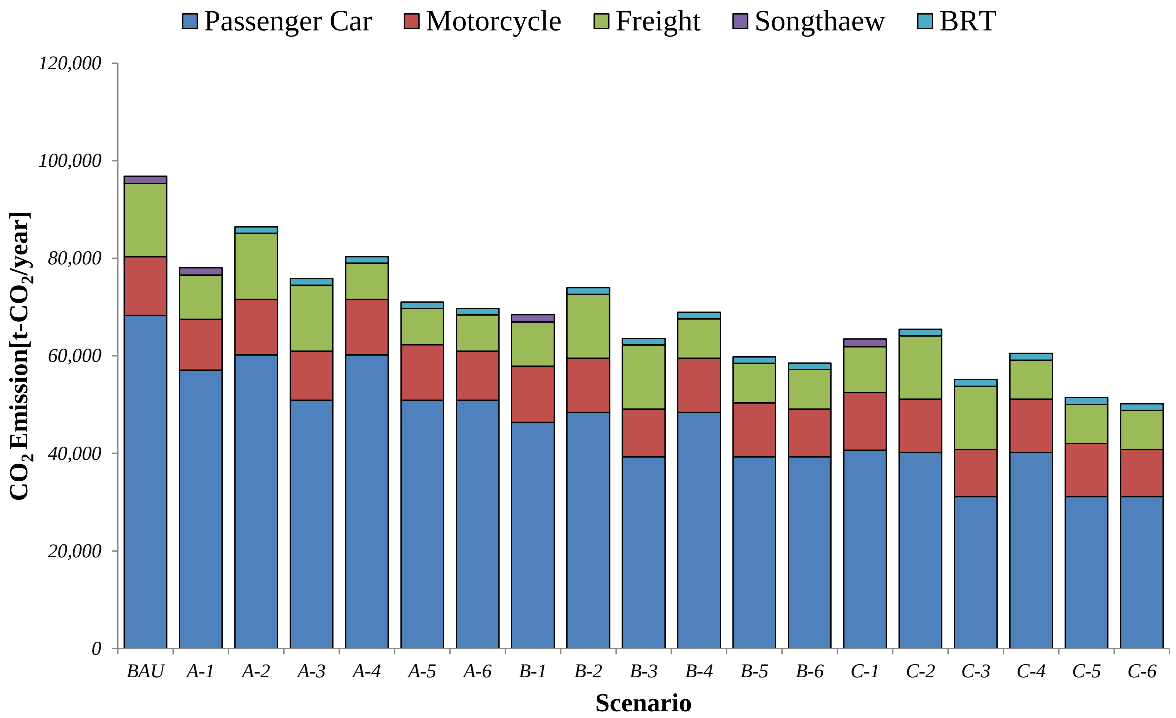

Figure 5. CO_2 Emissions of all scenarios

6. CONCLUSION

In this study, it was indicated that the scenario introduces TOD and BRT along with a shifting to electric freight vehicles and hybrid vehicles could that reduced the CO_2 emissions by up to 48.2%, as compared with BAU scenario. In addition, the CO_2 reduction effect was basically ineffective if only TOD policy, BRT, or shifting to electric vehicle was introduced in Khon Kaen city. Thus, we concluded that it is necessary to introduce the synthetic land use and transportation policy in the future for realizing a low carbon city.

In the existing research, there has been no estimation of the CO_2 emission with TOD and other policies. But this study could build a scenario toward greater reduction of CO_2 emissions. In addition, case study in Khon Kaen is a middle-sized city of a developing country. Therefore, we can think that these scenarios could be adopted in many cities of developing countries.

Further studies are needed to estimate the CO_2 emissions for developed terminal traffic along BRT lines and reallocated logistic facilities, and construct a modal choice model for increasing accuracy of future modal share.

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