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

Paper Identification number:YRF13-036

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Abstract

In recent years, realization of a Low Carbon Society is strongly required to prevent global warming. Especially in small and medium-size developing cities in Asia, rapid growth of auto mobiles have increased greenhousegases(GHGs) emission significantly. To tackle with this problem, those cities are trying to introduce rail or guide way public transport. However, it is not always sufficient to prevent increasingCO_2 emissions.Thus, it is important to implementa comprehensive policy which includes effective land use policy and low carbon public transportation policy in the early stages of city development. In this study, three strategic policies were considered; namely introduction of Transit Oriented Development (TOD), introduction of Bus Rapid Transit (BRT), and conversion from fossil fuel powered vehicles to electric vehicles and/or hybrid vehicles. The scenario is set to consider the potential strategies which would contribute for reduction of CO_2 emission. Therefore, CO_2 emissions were estimated by applying some those policies such as TOD and BRT used electric vehicles, hybrid vehicles and ethanol buses in KhonKaen City, Thailand based on some forecast scenarios. As a result, it was indicated that the scenario introduced TOD and BRT with shifting to electric freight vehicles, hybrid vehicles could be reduced the CO_2 emissions by up to 48.2% as compared with Business As Usual (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 comprehensive land use and transportation policy in the future for realizing low carbon city.

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 which are one of main carbon dioxide (CO_2) emission sources have rapidly increased in many small and medium-sized cities (urban population from 0.20 to 2.0 million)of the developing countries because there is no rail or guide way based public transportation in those cities. In addition, urban area is spreading out because of rapid economic growth. Thus, it's important to implement comprehensive policies which are composed with effective land use plan such as Transit Oriented Development (TOD) together with introduction of rail or guide way based public transportation in the early stages of city development. However, CO_2 reduction through those kinds of policies has never been realized in such developing cities.

Therefore, in this study, the impacts of introducing comprehensive policy including introduction of BRT using Ethanol Buses, TOD, and conversion from fossil fuel powered vehicles to electric vehicles or hybrid vehicles on CO_2 reduction were estimated.

As the case study of medium-sized city, KhonKaen city, Thailand was selected because 5 routes of BRT will be introduced by 2022.

2. Literature Reviews

Several studies evaluated the effect of CO_2emission 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 policy has been dealt with under the different methodology in each study.

Many researchers focused on TOD policies and tried to evaluate the amount ofCO_2 emission reduction. For example, Min, et al. (2007) compared the CO_2 emission reductions applying TOD policies or Auto Oriented Development (AOD) 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 meters from station of public transportation. 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 in the case of TOD than AOD, and the vehicle kilometer of traveled was also decreased.

In order to develop methodology to evaluate land use policy and public transportation simultaneously, several studies tried to employ bi-level traffic demand model. One of those researches was developed upper model which maximizes possible trips subjecting to the environmental capacities and travel behavior that defined a sa lower model employed the general equilibrium assignment model withinte grating modal choice and trip assignment model to express suitable economic activities and travel demand from upper model. Based on this concept, for example, Gojash, et al. (2007) estimated the maximum possible trips under an emission constant in the case of Chengdu, China. As the result, the optimal solutions were indicated by using the model. However, to calculate the optimal solution, many assumptions are required so that it is rather difficult to include many policies and technological innovation.

Traditional traffic demand forecasting model have been used to evaluate CO_2 emission reduction by improvement of transportation facility and services in many studies. However, because of limitation of freight transportation data, only few studies dealt with freight transport as well as passenger transport. For example, Kaneko, et al. (2005) developed truck OD table based on in-bound and out-bound survey of truck by department of land transport (DLT) in Bangkok, and then also calculated traffic demand and road side emission using the multi-mode user equilibrium model. However, in-bound and out-bound survey of truck has not been conducted long time in Bangkok and there is no other effective data which represents freight transport or truck movement in Bangkok. In most of cities, situation is worth, so it is impossible to estimate the impacts of any policies of technological innovation regarding freight transport in most of cities.

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 was not included TOD policy or technological innovation.

Therefore, in this study, we try to estimate the amount of CO_2 reduction under the combination of several policies such as TOD policy, public transit policy, technological innovation, and freight traffic. This study is expected to provide some important outcomes for the medium-sized cities of Asia counties.

3. OverviewinKhonKaen City

3.1 Current Traffic Situation

In KhonKaen 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 bus due to the failing introduction of local buses. At present, 751 Songthaews converted from trucks run in KhonKaen city as the main public transportation.

3.2 Plan of BRT

KhonKaen city developed the plan to introduce 5 BRT routes in the central area of the city, route by route, during 15 years from 2007 to 2022 (Fig. 1). In the first five years, main 3 BRT routes (Red Line, Blue Line and Pink Line) will be constructed with 63 buses, and then 2 BRT routes (Green Line and Yellow Line) will be constructed 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.

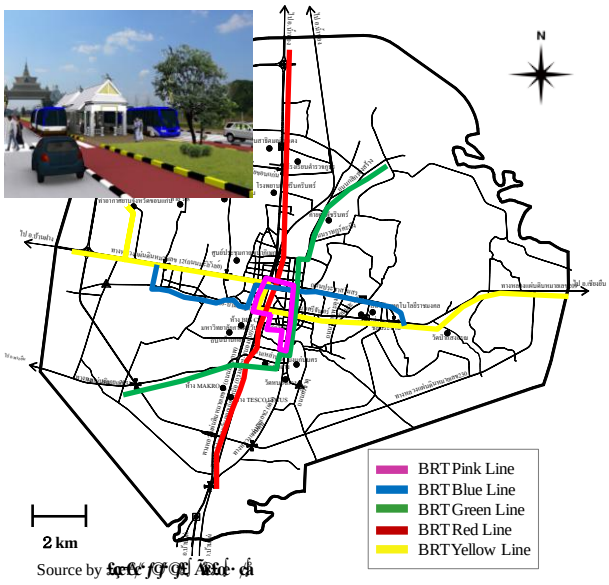

Fig. 1 Plan and image of BRT in KhonKaen city

3.3 Necessity of Introducing TOD in KhonKaen

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, the population in the center of the city 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. Fig. 2 shows the future image of population density in the whole KhonKaen city introduced TOD policy in 2030. This image was estimated for this study based on the concept proposed by Calthorpe (1993).

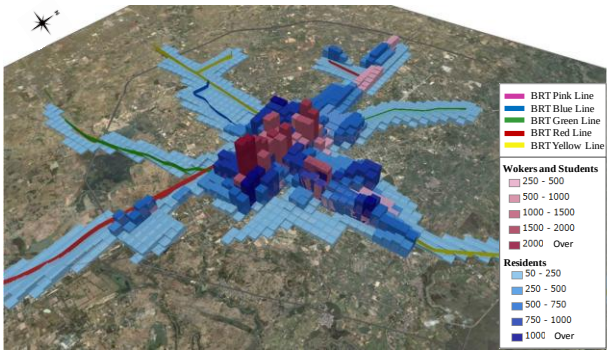

Fig. 2 Future image of population density with TOD in 2030

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 Fig. 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 KhonKaen, 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.

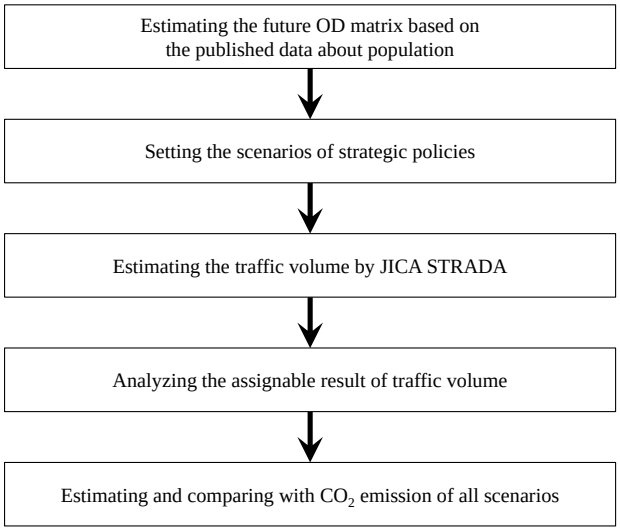

Fig. 3 Flow of evaluating CO_2 emissionreduction

4.2 Introduction of Strategic Policy

The idea to organize policies and technologies for achieving a low carbon transport system in Urban Transport and the Environment (CUTE) matrix systematically was proposed by the World Conference on Transport Research Society (WCTRS).

In the project of "Research into concrete measures to establish a low carbon transport system in Asia (S6-5 project), CUTE matrix was employed to select available policies and technologies in year 2030 and 2050. These policies and technologies are classified into three main categories: AVOID(avoid unnecessary transport demand), SHIFT (shift to low carbon means of transport), and IMPROVE(improve transport energy consumption efficiency).Further, classifications are made according to the means by these policies and technologies are achieved :technological, regulatory, informational, and economic (Table1).

Table1 CUTE matrix of strategic policy[17]

Strategies / Instruments	AVOID	SHIFT	IMPROVE
Technological	• Transport oriented development (TOD) • Poly-centric development • Efficient freight distribution	• Railways and BRT development • Interchange improvement among railway, BRT, bus and para-transit modes • Facilities for personal mobility and pedestrians	• Development of electric vehicles • Development of biomass fuel • "Smart grid" development
Regulatory	• Land-use control	• Separation of bus/para-transit trunk and feeder routes • Local circulating service • Control on driving and parking	• Emissions standards • "Top-runner" approach
Informational	• Telecommuting • Online shopping • Lifestyle change	• ITS public transport operation	• "Eco-driving" • ITS traffic-flow management • Vehicle performance labeling
Economic	• Subsidies and taxation to location	• Park & ride • Cooperative fare systems among modes	• Fuel tax/carbon tax • Subsidies and taxation to low-emissions vehicles

In this study, three strategic policies were considered: 1) Introduction of TOD (AVOID), 2) Introduction of BRT (SHIFT), and 3) Conversion from fossil fuel powered vehicles to electric vehicles, and hybrid vehicles (IMPROVE).

4.3Scenario Setting

In this study,18 scenarios were set to examine the conventions ofselected policies and technologies as shown in Fig. 4 and Table 2. Basically 3 main scenarios were set based on difference of degree of TOD, namely, A: 10%, B: 30%, and C: 50%. This is supposed that reproducing the situation of movement of the people to along BRT lines (AVOID).

It is assumed that all BRT lines are constructed in 2030. In the case with BRT, the existing Song-thaew route is discontinued, and then we had an assumption that all passenger of Song-thaew shift to BRT (SHIFT). We also hypothesized that the technological innovation for vehicles with engines would have occurred and EV/HV would be used more in near future. Therefore the conversion rate to EV/HV from fossil fuel powered vehicles was considered: 0%, 30% and 50%. Based on trend of EV/HV in Thailand, truck and motorcycle would shift to EV, and passenger car would also convert to HV. The conversion rate was 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 in Japan or Thailand(IMPROVE).

Regarding the Scenario 1, the Song-thaews 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.

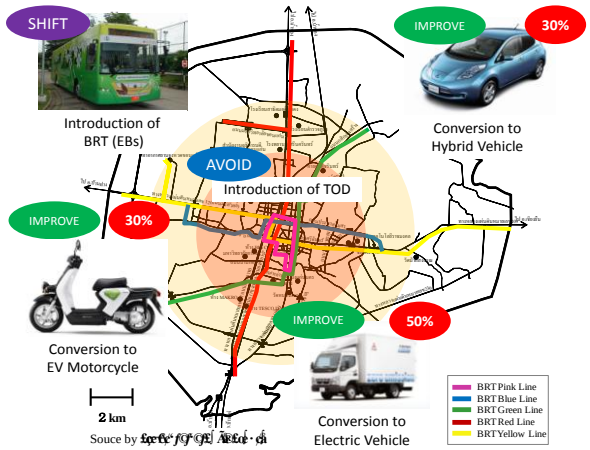

Fig. 4 Image of scenario in this study

Table 2 Scenario setting in this study

Scenarios		TOD[%]	Introduction of BRT (EB)	Conversion ratio to Freight(EV)[%]	Conversion ratio to PC(HV)[%]	Conversion ratio to MC(EV)[%]
BAU		0		0	0	0
A	1	10		50	30	30
	2		✓	0	0	0
	3		✓	0	30	30
	4		✓	50	0	0
	5		✓	50	30	0
	6		✓	50	30	30
B	1	30		50	30	30
	2		✓	0	0	0
	3		✓	0	30	30
	4		✓	50	0	0
	5		✓	50	30	0
	6		✓	50	30	30
C	1	50		50	30	30
	2		✓	0	0	0
	3		✓	0	30	30
	4		✓	50	0	0
	5		✓	50	30	0
	6		✓	50	30	30

4.4Demand Forecasting

The future OD matrix in 2030 in Business As Usual (BAU) was 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.

In addition, although there is no OD matrix data about freight of Khon Kaen, the recorded number of the pickup truck used by freight in many cases was over 20%.Thus, it is necessary to take the freight flow in this estimation.Then, the freight occurrence concentrated traffic volume and the freight OD of the city based on surveyed of the business place by Mizuguchiof Nihon University and Thaned et al. of the Khon Kaen University were used in this study. Concretely, the number of industrial classification business places was extracted for every large zone which collected the zone used on the person trip, 133businessplaceswere extracted from these business places, and interview survey to the business proprietor about freight traffic was conducted. As the result, it was reported that the data about the type of industry, the kind of vehicles, the origin and place of arrival (the type of industry, the zone number , the location) and the delivery frequency was collected. The freight OD pattern of the present condition was estimated from the survey ,marginal distribution as the freight occurrence concentrated traffic volume estimated from the number of business places, and the freight OD of the city expanded by the frater method.

The OD matrix under introduction of TOD was calculated in assumption of generated trip converted from all zones to the zones along BRT lines.

On the other hand, 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 through 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 was solved by satisfying the requirements of

network equilibrium expressed by the following mathematical optimization equations.

$$\min . Z(x(f), q, O) = \sum_m \sum_a \int_0^{x_a^m} t_a^m(\omega) d\omega + \sum_{rs} \sum_m \sum_p \sum_k \frac{1}{\theta_1^p} f_{m,k}^{rs,p} \ln\left(f_{m,k}^{rs,p} / q_m^{rs,p}\right) + \sum_{rs} \sum_m \sum_p \frac{1}{\theta_2^p} q_m^{rs,p} \ln\left(q_m^{rs,p} / q^{rs,p}\right) + \sum_{rs} \sum_m \sum_p q_m^{rs,p} C_m^{rs,p} \quad (1)$$

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$m$ for OD pare between zone r and s.

When the optimization problem was 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.

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

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 traffic volume, was then compared with the observed freight traffic volume of Khon Kaen City. As shown in Fig.5, the estimated values of the model were very close to the observed one, which supports the accuracy of the model.

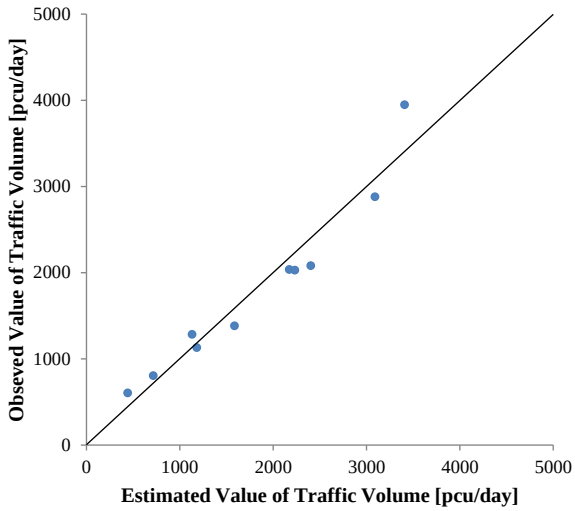

Fig. 5 Correlation analysis of observed and estimated value of freight traffic volume

4.5 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:

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

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

where,

$m \in M$: m is the set M of available Mode between OD pare betweenzone r and s,

$r \in R$: r is the member of the set R oforigin,
$s \in S$: s is the member of the set S ofdestination,
q_{rs}^{m}: trip distribution by mode betweenzone r and s,
l_{rs}^{m} :shortest distance by mode betweenzone r and m,
EF_{rs}^{m} : emission factor of CO_2 by vehicletype,
$V_{rs,m}$: average speed by vehicle typebetween zone r and s,
a^m,b^m,c^m: parameters of emission factor by vehicle type.

5. Results

As a result, shown in Table 3 and Fig. 6, the C-6 scenario which include TOD, BRT with ethanol bus, could shift to electric vehicles and hybrid vehicles, and electric motorcycles could reduce 48.2% of CO_2 emission which ismaximum case.

In comparison with scenario 1 and 6 over A, B and C, the effect of introducing BRT is expected around 10%. In addition, if TOD policy was introduced, CO_2 was reduced around 10% in scenario A, 20% in scenario B, and 30% in scenario C respectively.

Regarding technological innovation, as mentioned conversion rate from fossil fuel powered vehicles to EV and HV, the effect of converting freight trucks to EV was 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.

Fig.6 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 3 Results of the amount of CO_2 emissions in all scenarios

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

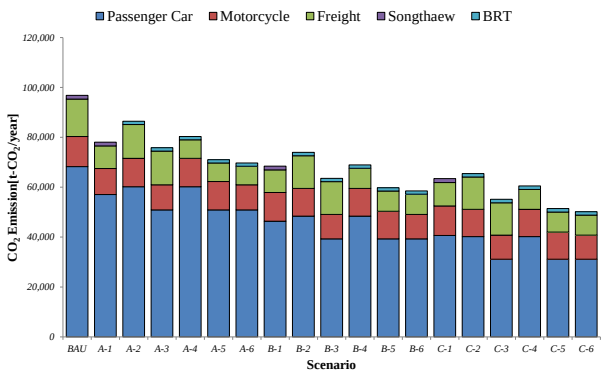

Fig. 6CO_2 Emissions of all scenarios

6. Conclusion

In the study, we could estimate the CO_2 emission reduction with the comprehensive policy including TOD, BRT and other measures in Khon Kaen city as a case of a medium-sized city in a developing country. It was found that the scenario introducing TOD and BRT with penetration of electric vehicles and hybrid vehicles could reduce 48.2% of CO_2 emissions, as compared with BAU scenario. However, CO_2emission reduction was rather small if only single policy or technical innovation was applied in Khon Kaen city. Thus, we concluded that it is strongly necessary to establish the comprehensive plan in which land use

plan, rail or guide way transport and technical innovation are included to realize a low carbon city.

On the other hand, we collected freight transport data on estimation of transportation demand by our survey in order to estimateCO_2 emission of freight which is necessary to evaluate the comprehensive policy in Khon Kaen city. Even our approach require much data such as emission factors, land use pattern, OD data for freight transport, etc. but very transparent so that it will be able to apply to any other small and medium-sized cities in developing countries.

Establishment of road map to realize the estimated low carbon city in year 2030 from existing situation is issue to study in future.

7. Acknowledgment

This research was supported by the Environment Research and Technology Development Fund(S6-5)of the Ministry of the Environment, Japan.

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