Possibility to Realize Low Carbon City in Medium-sized City of Asia: Case Study in Vientiane, Lao People's Democratic Republic

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Abstract: In Vientiane, many urban transport studies have been carried out to solve growing traffic problems and many countermeasures such as introduction of bus rapid transit (BRT), loop bus, and parking management in the downtown, etc., have been proposed. In this study, the impact of conjunctions of such proposed measures on CO_2 emission reduction in the year 2030 were estimated. Particularly, to estimate future demand for BRT under different land use patterns, the mode choice model was developed based on the result of the interview survey. As a result of estimations, around 23% of CO_2 emissions could be reduced by introducing BRT and transit oriented development (TOD) as well as technological innovations such as hybrid vehicle and electric motorcycle in the market. Finally, possibility to realize low carbon city in Vientiane was discussed based on the result of estimation.

Keywords: Low carbon city, CO_2 emission reduction, BRT, TOD, Technological innovation

1. INTRODUCTION

Vientiane, the capital of Lao People's Democratic Republic is a typical middle-sized city in Asia and has been less dependent on motorcycles so far. However, recently, the numbers of passenger vehicles and motorcycles have been increased dramatically and traffic congestion during peak periods has become serious. Since the number of automobiles is expected to increase by 2035 because of economical growth and urbanization, many urban transportation studies are carried out by JICA, ADB, etc.. Many countermeasures are suggested, such as improvement of existing buses, BRT, loop buses, parking management, low emission vehicles, etc.. However, CO_2 emission reduction from each countermeasure is rather small, so that the impact of conjunctions of proposed countermeasure has to be examined.

Thus, in this study, the scenarios based on conjunctions of selected countermeasures were prepared, and their impacts on CO_2 emission reduction were estimated by using transportation demand forecasting models and emission factors together with assumption on technological innovation of electric vehicles. Based on comparison of estimated results, the possibility to realize a low carbon city in Vientiane was discussed.

2. LITERATURE REVIEW

In order to promote Environmentally Sustainable Transport (EST) in Asia, the Regional EST Forum was initiated by the United Nations Centre for Regional Development (UNCRD) and the Ministry of the Environment Japan. Vientiane was selected as one of the targeted cities under the program. To realize the goal of the program and to prevent serious traffic jams in the future, according to the JICA study (2008), the improvement of bus service and its network plan, the introduction of new transport system such as BRT, and LRT were proposed.

Some detailed studies of the proposed measures were done. For example, to find out an optimal system of BRT in Vientiane, 5 sets of combinations for BRT system were evaluated by applying cost-benefit analysis (Phanthaphap et al. 2008). There is also a study on proposing transit short-range planning and design of urban public transit and their financial simulation was also conducted (Sengsavath et al. 2009).

Until now, studies on Vientiane's urban transportation such as the optimization of public transport systems, network, and their financial analysis have been carried out. However, there are no studies on urban transportation estimated impact on environmental . Therefore, this study tries to evaluate on the environmental impact, mainly CO_2 emission reduction from the conjunction of the introduction of BRT, under the constraint on land use (TOD), and technological innovations (wide spread use of hybrid car and electric motocycle).

3. STUDY AREA

Vientiane is the capital city of Laos. According to the population census in 2005, around 690,000 people live in an area of 3,920km^2. Buses are the only public transport in the city, with the network as shown in Figure 1. According to the JICA report in 2008, the travel mode share of buses is just 4%, while the share of motorcycles and cars is around 60% and 11% respectively. As one of the bus service improvement projects, 42 new buses were granted by the government of Japan in May 2012. Most of them are operated on the main routes of existing buses. Introduction of BRT on 3 routes was proposed as shown in Figure 2. Among 3 routes, the route will connect the city center to the National University of Laos is expected to have potential for making a useful BRT route. Thus in this study we focused on this route.

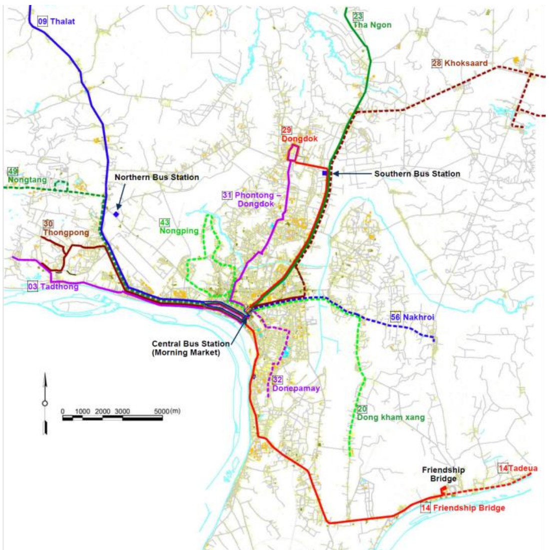

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Figure 1. Map of Bus lines in Vientiane

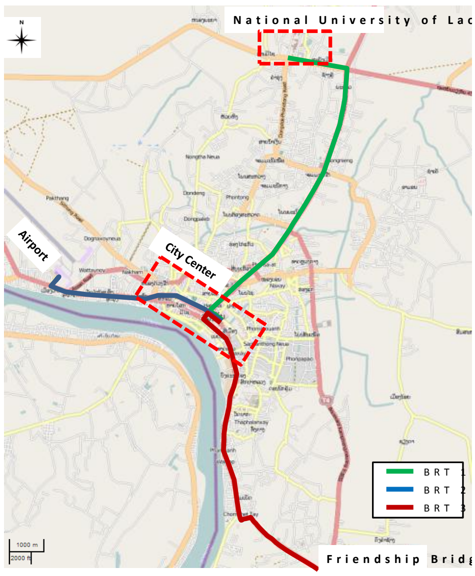

Figure 2. Map of proposed BRT lines

4. FIELD SURVEY

The data required for the analysis were obtained by four field surveys conducted in Vientiane. Figure 3 shows the survey points in this study.

The first survey was conducted on October 5th and 6th, 2010, and the data of traffic volume, traffic signal cycle length, and travel times were collected. Traffic volume was counted at 5 locations along the BRT route during the morning peak hours, from 6:30 to 8:30. The cycle lengths at 7 intersections with traffic signals were measured during the same period. Travel time was measured along the BRT route using GPS receivers installed in passenger cars.

On the second survey, the situations of on-street parking and off-street parking in the downtown area were observed by taking continuous photos at the city center on July 20th, 2011. In this area, parking on the street was prohibited and only a few parking places are available. Talat Sao mall, which is the largest shopping mall with 4,022m^2 of floor space, is the largest trip attraction point in the study area. The parking places servicing the mall were also surveyed on July 20th. Additionally, the traffic volumes on three additional locations in this area were observed during 30 minutes within the morning peak hours (8:00-8:30) on August, 29th. On the same day, traffic signal cycle length was also measured on three intersections located in the same area.

On the third survey, traffic volume and travel time were collected again on August 2012. Traffic volume was counted on three locations along the BRT route and on another three locations in the city center during morning peak hours (7:00-9:00). The travel time along the BRT route and in the city center was measured using GPS receivers installed in passenger cars during the same period. At the same time, a pre-survey of the stated preference of transport use was carried out by home interview survey along the planned BRT route.

As the fourth survey, for forecasting the people's travel behavior along the BRT route after the planned BRT is in operation, a stated preference survey was conducted on the 3rd and 5th of January, 2013. The survey area is shown in Figure 4.

Table 1. The contents of SP survey

Main concerns	Items of survey
Current travel behavior	Current using travel network Travel purpose
Intension to use BRT	Use or not use after BRT is in operation
Travel behavior after BRT implemented	Show the different travel time and travel cost for every alternative transport modes and let respondent select the most desirable choice
Individual and family attribute	Sex Age Driving license (car, motorcycle) Number of vehicles (car, motorcycle) Monthly income

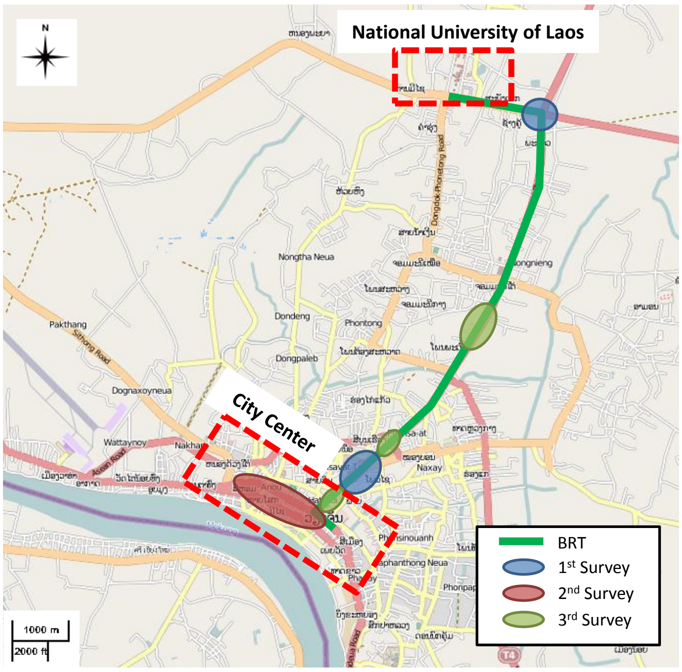

Figure 3. Survey points for this study

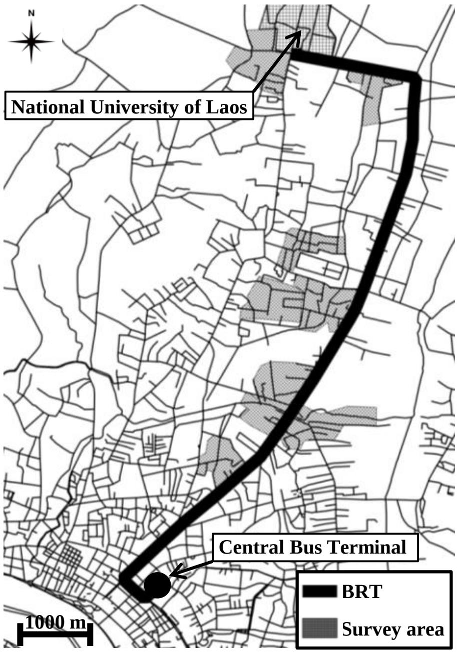

Figure 4 . SP survey area

5. METHODOLOGY

5.1 Scenarios setting

This study makes estimates into 2030 in the future. Scenarios estimating two or more combinations that assume the following cases. In addition, a scenario which enforces nothing is set to Business As Usual (BAU) scenario.

1) BRT is in operation
2) To analyze the impact of TOD, we assumed when 10%, 30% and 50% of people in Vientiane moved into the area along the BRT route.
3) In the introduced BRT route, two lanes will be occupied by BRT and traffic in other lanes might be congested. Thus, we assumed the expansion of road on the BRT route
4) According to JICA study (2012), hybrid cars and electric motorcycles are expected to penetrate into the market. Thus, we assumed 30% of cars might be replaced hybrid cars and 30% of motorcycles might be replaced electric motorcycles.

5.2 Future traffic demand

In this study, traffic demand expressed in the OD matrix was estimated at 2010 and 2030 respectively. The demand for 2010 was estimated by interpolation between the OD tables for 2007 and 2013, which were developed in the previous JICA study in 2008 (JICA, 2008). The demand for 2030 was estimated based on expected growth rates of total number of trips, by vehicle types, which were obtained as approximate expressions to the OD table for 2007, 2013, 2017, and 2025. Growth rates of total number of trips by vehicle types are shown in Figure 5.

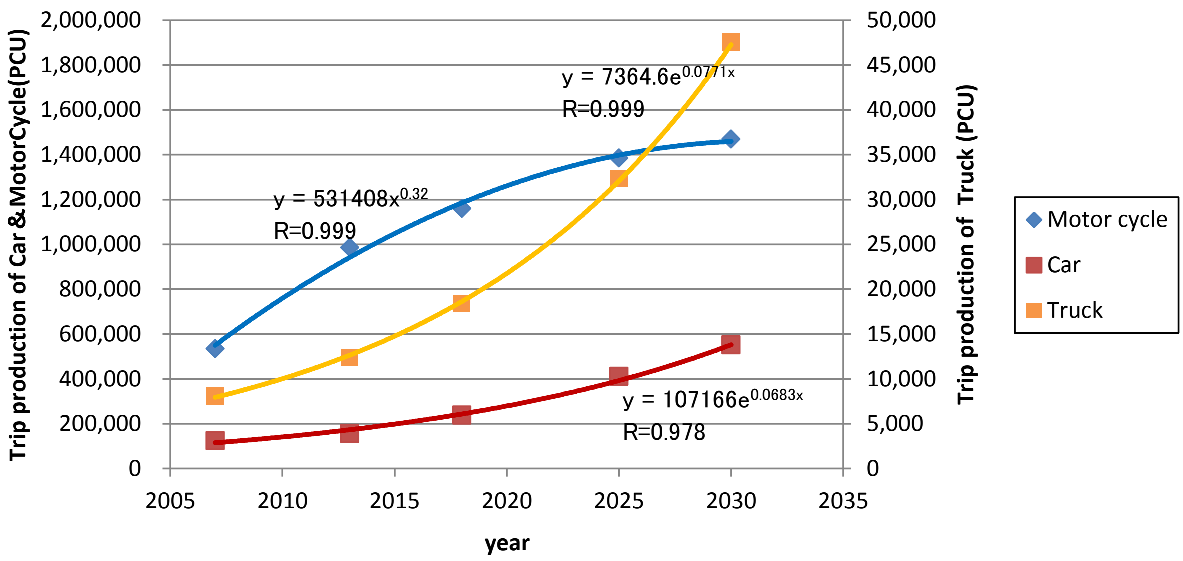

Figure 5. Approximation expression of total trip by vehicle types

5.3 Development of OD table considering TOD policy

As mentioned above, to represent TOD policy, 10%, 30% and 50% of people have to move to the area along BRT route. Thus, our OD table developed the three cases by transferring 10%, 30% or 50% of generated and attracted trips from the zones outside of the BRT route to the area along BRT route zones. Then, the OD table after the introduction of TOD was produced by using the frater method based on the existing trip pattern. This process is shown in Figure 6.

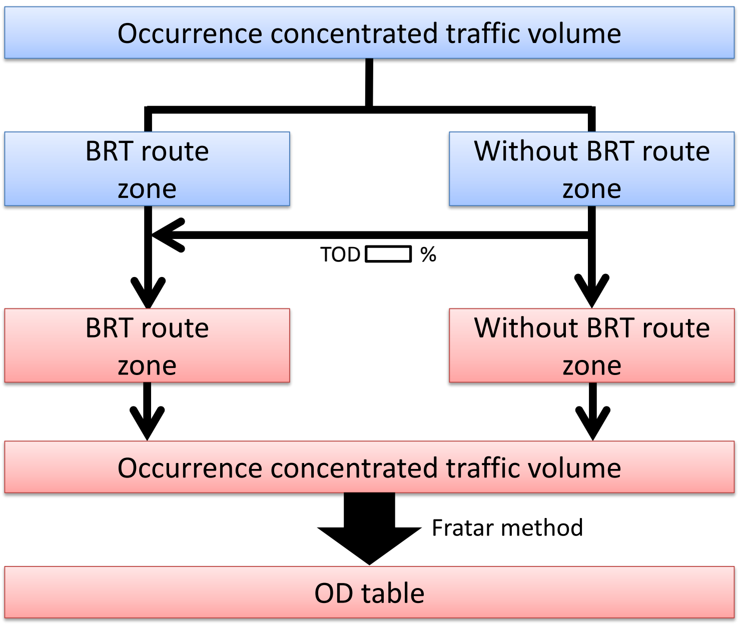

Figure 6. Method of Reincarnation of TOD

5.4 Forecasting Modal Split

The multinomial logit model (MNL model) with the alternatives of car, motorcycle, BRT, and bus was formed as a mode choice model. The tree structure of the MNL model is shown in Figure 7. And the MNL model is shown in Equation (1) and (2). The parameters of the utility functions were estimated by using NLOGIT software. The modal split were conducted using the model shown in Table 2.

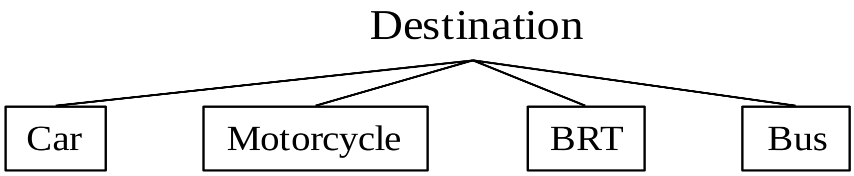

Figure 7. The structure of the MNL model

$$p_{in} = \frac{\exp[V_1]}{\exp[V_1] + \exp[V_2] + \exp[V_3]} \tag{1}$$

$$V_{in} = \beta_1 Z_{1i} + \beta_2 Z_{2i} + \ldots + \beta_k Z_{ki} \tag{2}$$

where,

P_{in} : Probability that individual n will choose alternative 1

V_{in} : The fixed term of utility relating to alternative i

Z_{ki} : The explanatory variable for the alternative i (For example cost, time)

β_k : The parameter of number k explanatory variables.

Table 2. Result of the MNL model

Variable		Coef.	t-stat.
Constant	(Car)	-0.50800	-2.159
Constant	(BRT)	0.66983	3.850
Travel Time	(Car, Motorcycle	-0.09396	-4.737
Travel Time (Excludes waiting	(BRT, Bus)	-0.09663	-6.222
Waiting time	(BRT, Bus)	-0.06268	-4.846
Travel cost		-0.000054	-1.960
Summary statistics			
N		444	
L(β)		-511.2009	
L(0)		-615.5147	
ρ^2		0.16572	

5.5 CO_2 Emission

The micro simulation model provides the average speed in all links of the studied network. This speed are provided along with the vehicle type dependent emission coefficients, the emission factor for a vehicle of that type on the given speed, according to Equation (3).

The link lengths, traffic volumes estimated in the travel demand model, and the emission factor obtained from Equation 3 were introduced as input parameters in Equation 4 in order to evaluate CO_2 emission.

The emission coefficients for Vientiane were not available; therefore, the coefficients obtained from Bangkok, Thailand (JTCA, 2003), were used. The similarities between the characteristics of the traffic of both cities justified this approach. The emission coefficients for hybrid vehicles are based on a study of the National Institute for Land and Infrastructure Management in Japan, titled "Investigation to estimation motor vehicle emission factors using environment impact assessment" (Japanese).

Table 3 shows the emission factors used in the CO_2 estimation, calculated with Equation 3. The CO_2 emissions for electric vehicles were calculated from the CO_2 emission intensity of Laos and the amount of AC power consumption rate of HONDA EV-neo. In Laos, 99% of the electricity is being produced by hydropower. Therefore, the CO_2 emissions intensity is assumed to be zero. As a result, the CO_2 emissions in electric vehicles were zero. The CO_2 emissions for BRT were calculated under the assumption shown in Table 4, and the emission factor uses the value of bus from Table 3.

Table 3. Emission coefficients for Bangkok, Thailand

Transport mode	a	b	c
Car	0.0585	-7.4522	336.22
Motor Cycle	0.0308	-3.6385	165.98
Truck	0.0688	-9.0791	457.52
HV	0.021	-2.3378	132.42
Bus	0.0378	-4.2744	178.78

$$Ef_{ki} = aV^2 + bV + c \qquad (3)$$

$$CO_2 Emissions = \sum\sum D_k \times T_{ki} \times Ef_{ki} \qquad (4)$$

where,

k : Link number,
i : Vehicle,
D_k : Length of link (km),
T_{ki} : Link traffic volume (vehicles / day), and
Ef_{ki} : Emission factor.

Table 4. BRT operation assumption

Length	11.5km
Average velocity	40km/h
Operating time	12h
Headway	5mn (Peak) 10mn (Off-peak)

6. RESULTS

Table 5 shows the estimation results from each scenario, and Figure 8 shows CO_2 emission by vehicle type. The BRT users were increased by implementing TOD. In particular, scenario B (BRT&TOD 30%) had the highest CO_2 reduction rate, compared with other scenarios. Although scenario C (TOD 50%) had a larger population than scenario B (TOD 30%), it caused traffic jams and increased car and motorcycle users. As a result, the average speed of the entire city was lower than scenario B. Scenario B-4 was the best scenario for reducing CO_2 emissions because the concentration of population by TOD policy was well-balanced. As a result, it was shown that the B-4 scenario could reduce around 23.5% of least CO_2 emissions, compared with BAU scenario.

Table 5. CO_2 Emission on each scenario

Scenarios	TOD[%]	Introduction of BRT	Road Expansion	Conversion ratio to PC(HV)[%]	Conversion ratio to MC(EV)[%]	CO_2 Emission [t-CO_2/day]	Amount of change from BAU[t-CO_2/day]	Reduction rate of change from BAU[%]
BAU	0			0	0	294.0	-	-
O-1	0	✓		0	0	322.6	28.6	9.7
O-2	0	✓	✓	0	0	317.3	23.3	7.9
O-3	0	✓		30	30	255.0	-39.0	-13.3
O-4	0	✓	✓	30	30	251.0	-43.0	-14.6
A-1	10	✓		0	0	309.2	15.2	5.2
A-2	10	✓	✓	0	0	301.2	7.2	2.4
A-3	10	✓		30	30	244.4	-49.6	-16.9
A-4	10	✓	✓	30	30	238.2	-55.8	-19.0
B-1	30	✓		0	0	297.2	3.2	1.1
B-2	30	✓	✓	0	0	284.4	-9.6	-3.3
B-3	30	✓		30	30	235.3	-58.7	-20.0
B-4	30	✓	✓	30	30	224.9	-69.1	-23.5
C-1	50	✓		0	0	303.8	9.8	3.3
C-2	50	✓	✓	0	0	285.3	-8.7	-3.0
C-3	50	✓		30	30	239.9	-54.1	-18.4
C-4	50	✓	✓	30	30	225.3	-68.7	-23.4

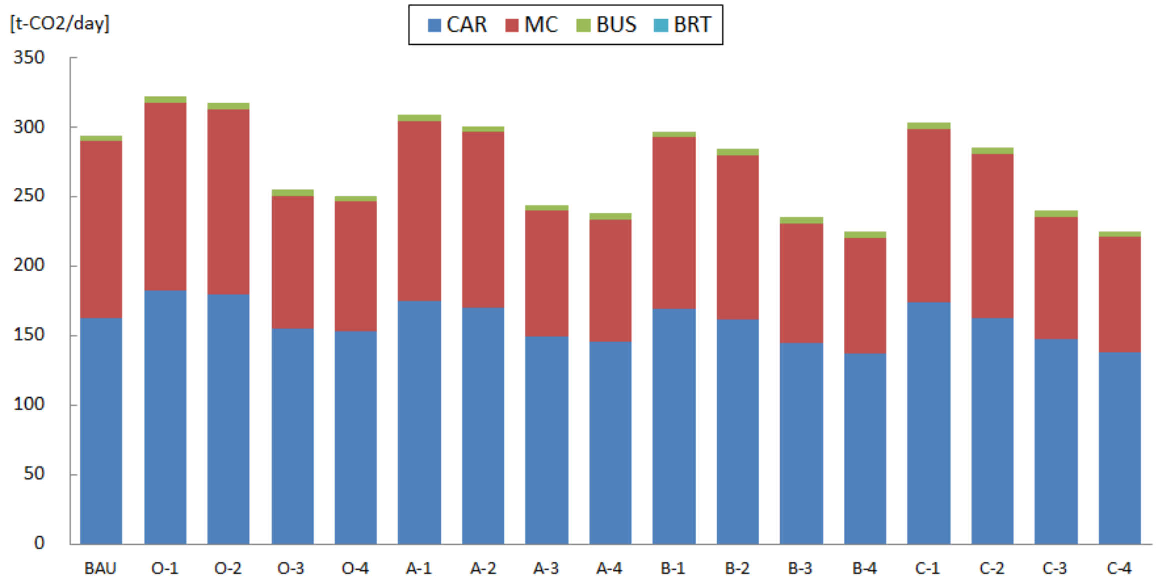

Figure 8. CO_2 Emissions by Vehicle Type

7. CONCLUSION

By estimating CO_2 emission reduction for different prepared scenarios, conjunction of countermeasures, namely introduction of BRT, introduction of TOD (0%, 10%, 30%, 50%), road expansion, market penetration of hybrid cars (0, 30%) and market penetration of electric motorcycles (0%, 30%) were evaluated. In this study, BRT is expected to be introduced on one route, and it is possible to reduce 23% of CO_2 emission compared with business as usual scenario in 2030, by putting together all other countermeasures.

If all three proposed BRT routes would be introduced and together with other countermeasures, like ethanol buses running by bio-ethanol , it is expected to reduce more CO_2 in Vientiane. Therefore, the authors could conclude that a low carbon city could be realized in Vientiane with the conjunction of countermeasures. The only question is the timing to introduce them. Further and more detailed analyses like the evaluation of the BRT network and the introduction of Park and Ride uses BRT should be done. These analyses would enhanced a feasibility for low carbon city in medium-sized City under a clear road map

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