Study on the Impact of CO_2 Emission Depending on Change of the Urban Structure: Case Study of Khon Kaen, Thailand

Hiroki KIKUCHI[a], Atsushi FUKUDA[b], Tuenjai FUKUDA[c]

[a] Graduate School of Science and Technology, Nihon University

[b] College of Science and Technology, Nihon University

[c] Research Institute of Science and Technology, Nihon University

739D 7-24-1 Narashinodai, Funabashi City, Chiba 274-8501, Japan

+81-47-469-5355

cshi13008@g.nihon-u.ac.jp/fukuda.atsushi@nihon-u.ac.jp/

noynoifukuda99@gmail.com

ABSTRACT

To realize the Sustainable Low Carbon Transport (SLoCaT) in a developing city, the long-run policy including not only introduction of public transport but also effective land-use plan such as Transit Oriented Development (TOD), compact city, etc. as well as technological innovation for vehicles and introduction of renewable energy should be established and evaluated in terms of energy consumption structure and modal share. Thus, in this study, the relationships between urban structure and travel activities based on available transportation mode such as Vehicle Kilometers Travel (VKT), travel distance, etc. were defined and simulated the impacts of such relationships on changing the urban structure and carbon dioxide (CO_2) emission dynamically by using the system dynamics model. As the result of simulation, CO_2 emission were obtained in long term and impacts of each scenarios were estimated.

KEYWORDS

Khon Kaen, System Dynamics, CO_2 Emission, Change of the Urban Structure, Vehicle Kilometers Traveled, Number of Vehicles, Low Carbon Society, Estimation in Chronological Order

1. INTRODUCTION

In recent years, the shift to a Low Carbon Society is considered as a solution to the global warming problem. Particularly, transport sector which is one of main CO_2 emission sources have rapidly increased in big cities around the world. This is because many people are using their-own cars instead of unavailable rail or guide way based public transportation in those cities.

In addition, urban area is spreading out because of rapid economic growth and population explosion. Thus, it is important to implement comprehensive transportation policies which are taken account of the urban structure, population, Gross Regional Domestic Product (GRDP) and so on. However, CO_2 reduction through those kinds of policies has never been realized around the world. Therefore, the impacts of implementing comprehensive policy included changing the population density for 30 years on CO_2 reduction were estimated. A middle-sized city of Khon Kaen, Thailand was selected as a case study due to its incremental number of populations and vehicles as result of economic growth.

The purpose of this study is to estimate the impact of CO_2 emission based on VKT of vehicles that depends on change of urban structure and implementing the low carbon policies using system dynamics. The reason why this study was used system dynamics because it could estimate the feedback effects dynamically when the policies were implemented.

2. LITERATURE REVIEWS

To understand sustainable growth of a city from the view point of better air quality and low carbon, many system dynamics models which are mainly estimate energy demand, air pollution and CO_2 emission in an urban area have been developed. Chen, et al. (2006) estimated NOx emission by vehicle type in Taipei City from 1969 to 2005 using system dynamics model based on population and economic growth. Wang, et al. (2008) also developed urban transportation model in Dalian City, China and tested impacts of 5 policies on NOx emission. Duran-Encalada, et al. (2009) developed PROPOLIS model to discuss sustainable development in Puerto Aura, Mexico which allows to discuss policies in many sectors. Feng, et al. (2013) developed Beijing-STELLA Model to energy consumption and CO_2 emission by sectors and fuel types in Beijing, China and tested impacts of several scenarios regarding population and GDP growth.

Beside those studies, relationships between CO_2 emission and transportation activities in national or inter-regional level have been modeled based on system dynamics concept and policies regarding CO_2 mitigation were examined in long term. Stefano, et al. (2010) developed the energy model to find out sustainable transport system. Han, et al. (2008) developed system dynamics model for inter-city passenger transport in China and estimated energy consumption and CO_2 emission with three scenarios. Stepp, et al. (2009) discussed the role of the feedback effect of GHG mitigation policy on transport sector conceptually. Egilmez, et al. (2012) estimated CO_2 emission from highway in US with several scenarios as well.

On the other hand, some studies are about sustainable land use planning and urban growth. Shen, et al. (2009) discussed about assessment of sustainable land use policy in Hong Kong. Han, et al. (2009) developed the model combined system dynamics and cellular automata (CA model) for assessing about urban growth in Shanghai. But, these studies were taken particular note of allocation for land use only.

Although there have been several studies evaluated the effect of CO_2 emission reduction by implementing transportation policies. 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 the different methodologies in those studies.

3. IMAGE OF LOW CARBON SOCIETY IN KHON KAEN

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, namely: 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. In this project, three strategic policies were considered for Khon Kaen, namely: Introduction of Transit-Oriented Development or TOD (AVOID), Introduction of Bus Rapid Transit or BRT (SHIFT), and Conversion from fossil fuel powered vehicles to electric vehicles, and hybrid vehicles (IMPROVE) as shown in Figure 1

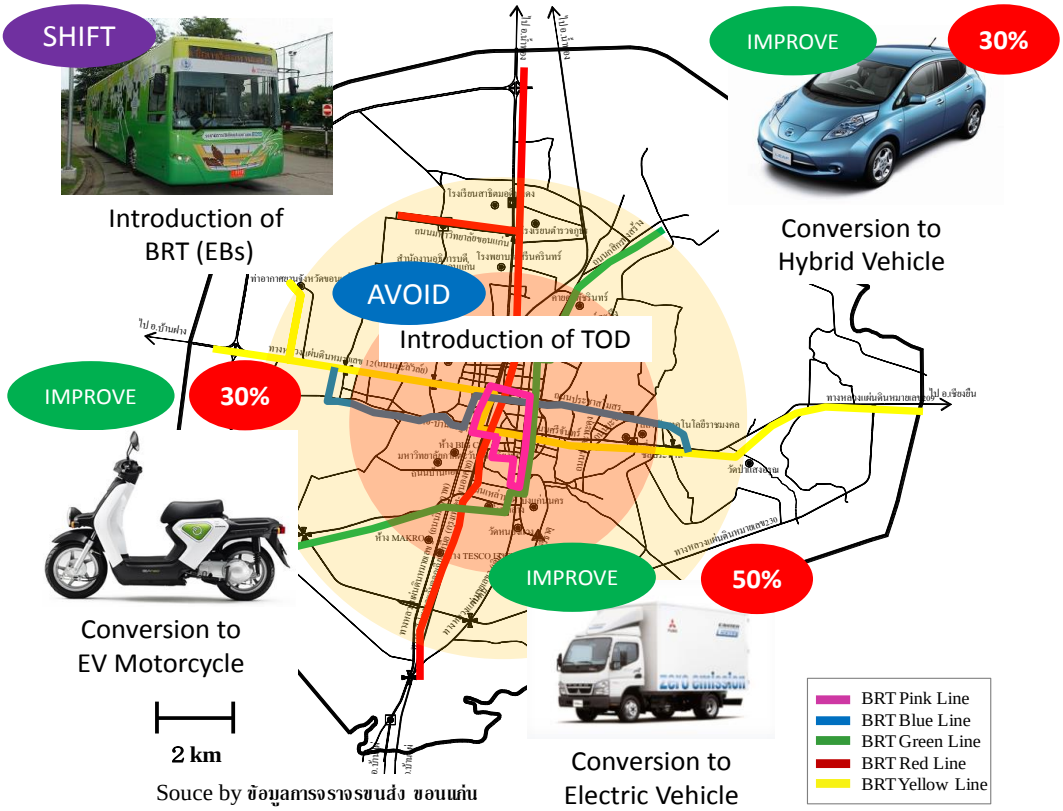

Figure 1: Image of scenarios in the project

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.

As a result, shown in Figure 2, the IMPROVE+SHIFT+AVOID scenario which include 50% TOD, ethanol BRT, and 50% electric vehicles and hybrid vehicles, could reduce 47.6% of CO_2 emission which is maximum case.

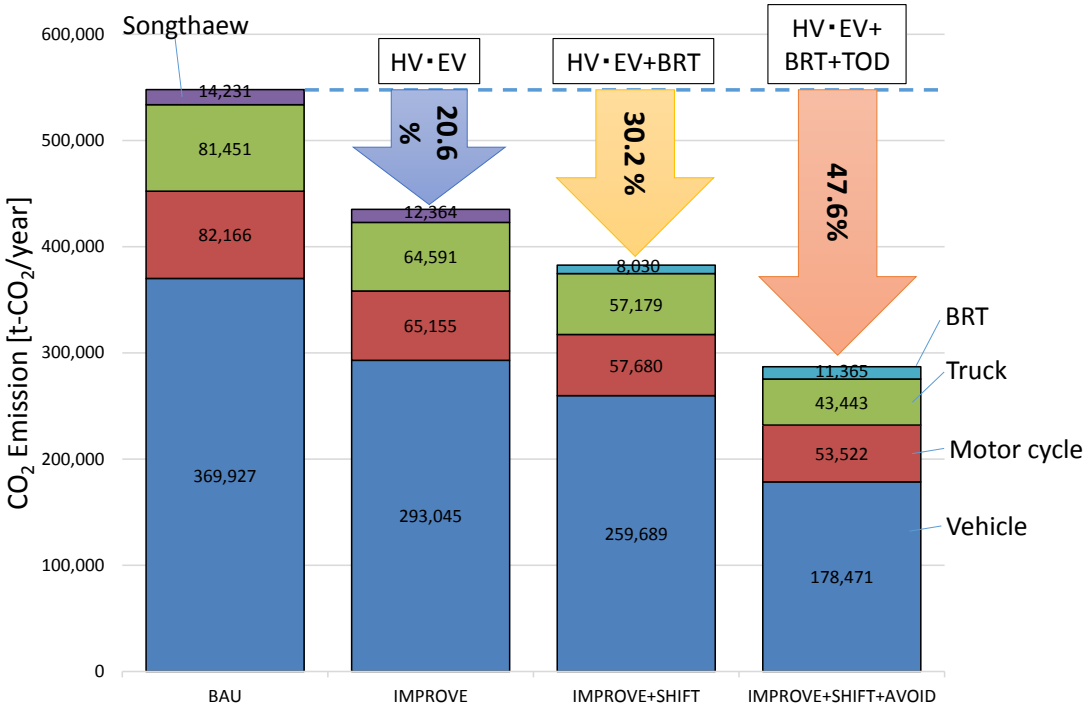

Figure 2: Summary of estimated CO_2 emission reduction

However, in this project, CO_2 emission could not estimate in chronological order. So it is important to estimate CO_2 emission in chronological order for implementing more concrete policies.

4. URBAN STRUCTURE AND TRAVEL ACTIVITY

Fukuda, et al. (2013) estimated VKT of Khon Kaen City and compared it to the VKT of different cities in Thailand, including Bangkok and Nakhon Ratchasima. These cities are different sized cities. The biggest city is Bangkok and the smallest city is Khon Kaen. As the results, shown in Figure 3, accumulated VKT of Bangkok was the highest among other cities.

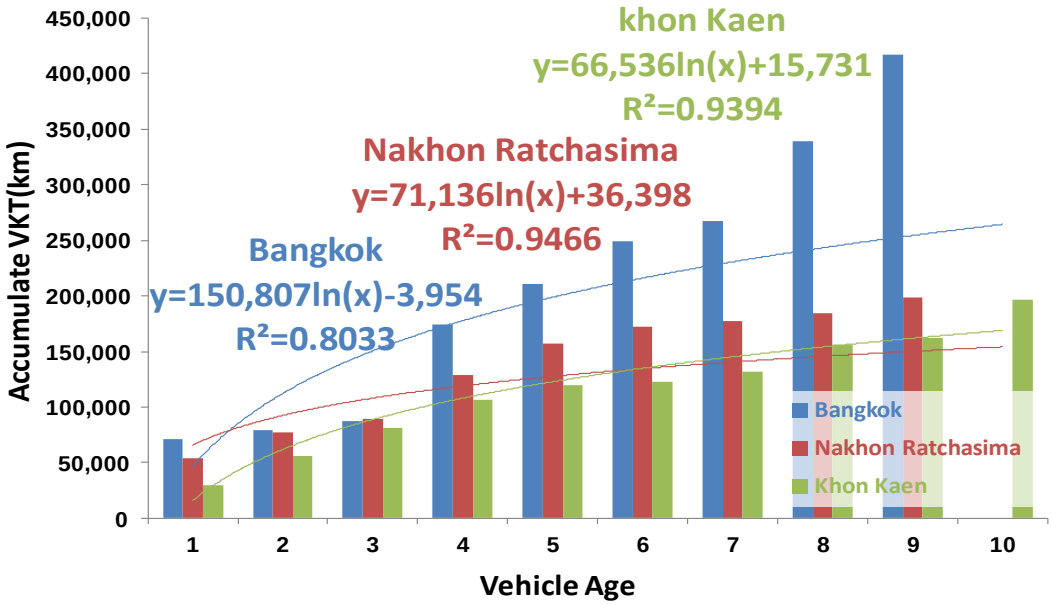

Figure 3: Estimated the VKT of different cities in Thailand

In addition, Cameron, et al. (2004) studied that the cause of increased VKT was shown to arise from population growth, urban sprawl, increased car ownership, and decreased vehicle occupancy in the seven case cities: Singapore, Hong Kong, Munich, New York, Stockholm, Phoenix, and Perth. As the results, especially, the cause of changing VKT was had effect on urban population, vehicle occupancy, and vehicle saturation.

As these existing researches, the larger in city area, population growth, and vehicle occupancy were higher VKT. So, in this study, it was taken particular note of changing the urban structure because of increasing the VKT is related to increasing CO_2 emission.

5. PROPOSAL OF MODEL

Case study

This study selected Khon Kaen, Thailand as a case study. Khon Kaen is located in the Northeast part of Thailand. The city has an area of 10,886 km^2. There are 1.77 million population with 163 people/km^2 density.

In the city, the number of registered vehicles had increased threefold between 2000 and 2012. 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.

Figure 4 shows the population and number of registered vehicles in Khon Kaen (Department of Provincial Administration, Ministry of Interior Thailand. Department of Land Transport, Ministry of Transport Thailand). As shown in the Figure 4, population and number of vehicles are inclined to increase between 2000 and 2012.

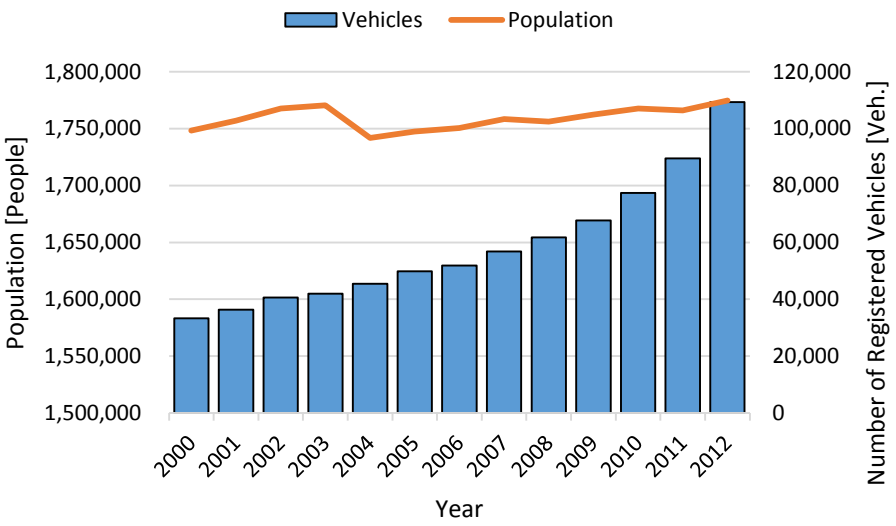

Figure 4: Population and number of registered vehicles in Khon Kaen

In response to these situations, Khon Kaen was selected as the case study.

Causal loop diagram

Causal loop diagram is determined the relationships of cause and effect. In this study, the proposed causal loop diagram is shown Figure 5. This diagram was constructed based on some existing studies (Han, et al. (2008), Wang, et al. (2008), Stepp, et al. (2009), Stefano, et al. (2010)) which were certified as sensitive models. Also, this diagram was taken into account regardless of the relationships between population, GRDP, total number of vehicles, urban area, VKT, and CO_2 emission. Especially, CO_2 emissions were calculated from fuel consumption and VKT. In addition, an incremental VKT occurred as a result of the change of urban area and increased number of vehicles respectively.

On the other hand, the growth of population, and GRDP had played a significant role in

generating an effect on increasing VKT and Number of Vehicles. Also, the growth of population, and GRDP had an impact on Transportation Investment and Total Lane Kilometers. If population and GRDP grow up positive or negative, Transportation Investment and Total Lane Kilometers will grow up positive or negative.

In addition, Average Fuel Economy, CO_2 Emission Factor, and Fuel Consumption changed associating with technical innovation were constructed in this diagram. If the change of technical innovation is bigly, CO_2 emission is decreased. These variables were very important to implement the Low Carbon policies.

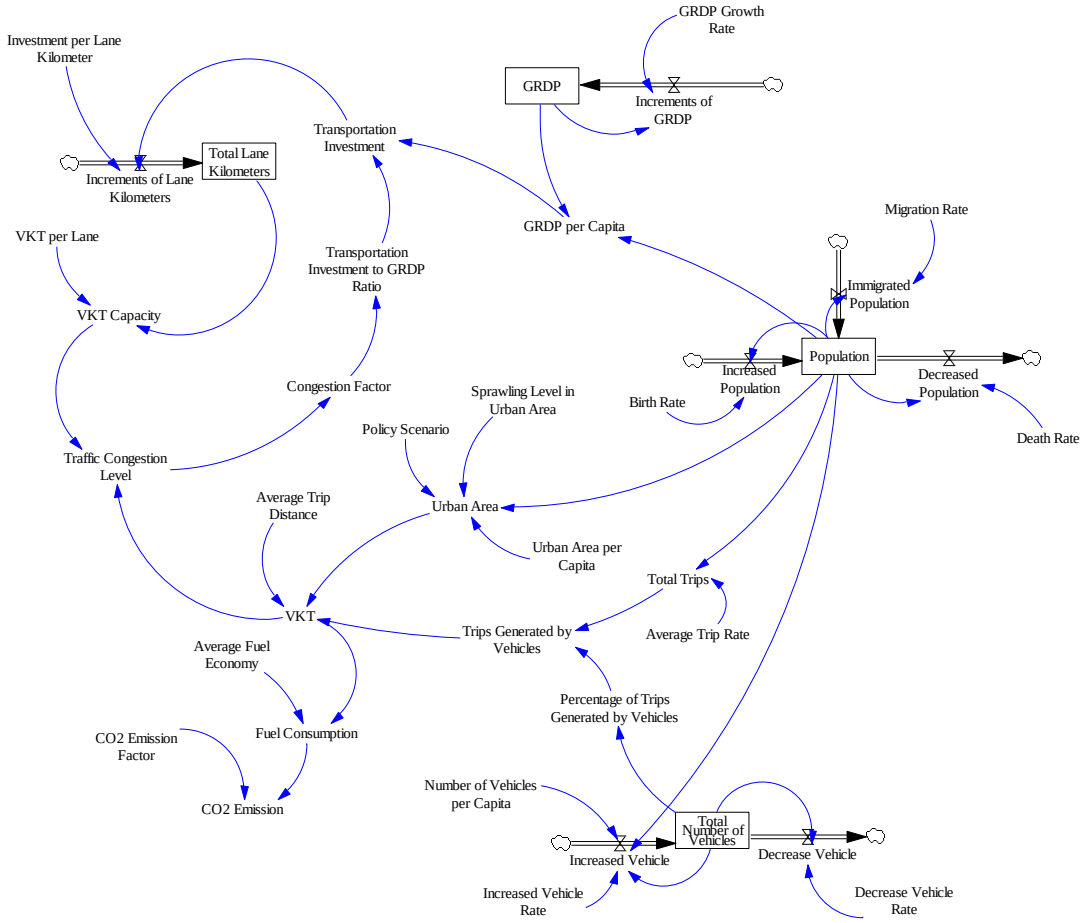

Figure 5: Causal loop diagram of the proposed model

In this study, it is estimated the impact of CO_2 emission due to change of the urban area, and VKT based on vehicles by using this diagram. Also, this study uses the base years of 1998, 2010 for model validation, and 2030 is set as the target year.

Data

Table 1 shows Overview of Variables for Causal Loop Diagram. These data were based on index published in the government report, since there is no statistical data examined by government and research agencies regarding middle-sized cities such as Khon Kaen. Especially, in this study, VKT per Lane, Investment per Lane Kilometer, and Average Fuel Economy were referred to estimate values of existing researches. But, the data on Sprawling Level in Urban Area, Average Trip Rate and Average Trip Distance were hypothesized values because of Khon Kaen had no these data.

Table 1: Overview of variables for causal loop diagram

Variables [Exchange rate: 1US$ = 30 Baht]	Value	Unit
GRDP Growth Rate	0.06	–
Migration Rate	0.0005	–
Birth Rate	0.012	–
Death Rate	0.008	–
Increased Vehicle Rate	0.136	–
Decreased Vehicle Rate	0.051	–
Number of Vehicles per Capita	0.062	vehicles/capita
Urban Area per Capita	0.0063	km^2/capita
Sprawling Level in Urban Area	1.25	–
Average Trip Rate	0.6	–
Average Trip Distance	20	km
VKT per Lane	240	VKT
Investment per Lane Kilometer	1.6	million US$
Average Fuel Economy	11.05	km/l
CO_2 Emission Factor	2.1896	t-CO_2/kl

Scenario design

In this study, 3 scenarios were set to examine the conventions of selected policies, namely, Business As Usual (BAU) scenario, Middle Density scenario, High Density scenario as shown in Figure 6. This is supposed that reproducing the situation of immigration of the people from suburban to central of downtown. Concentrated population to the central of

downtown leads to reduction of CO_2 emission because of total VKT are decreased. Also, main purpose of introducing these scenarios is impact of the CO_2 emission depending on the change of urban area.

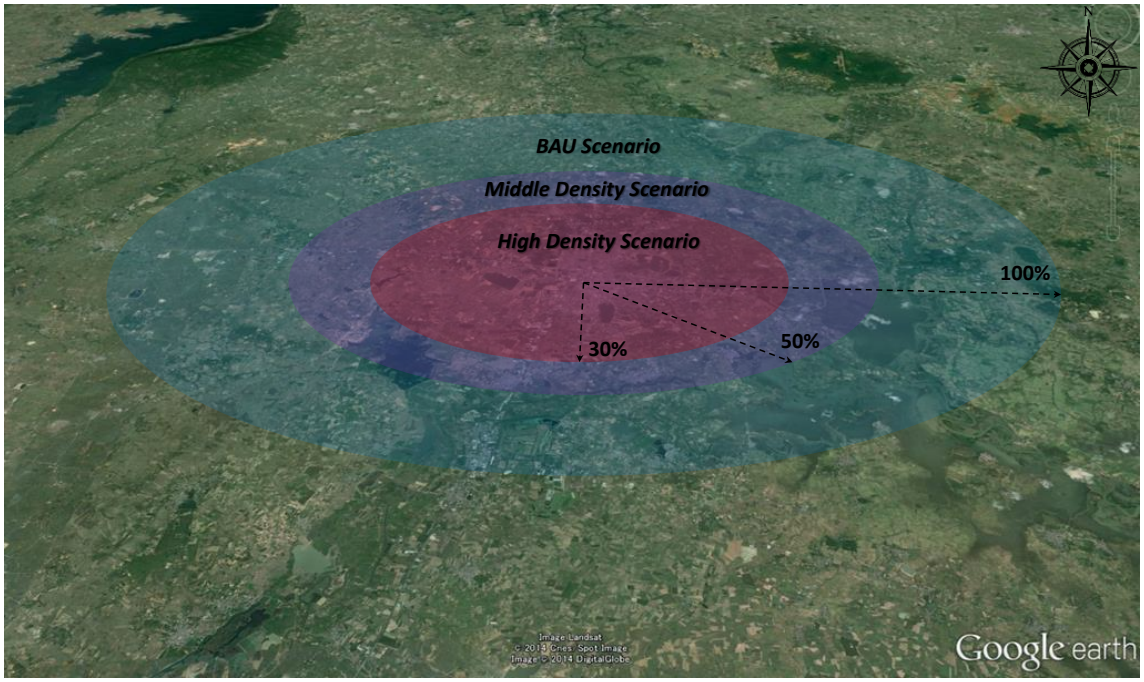

Figure 6: Image of scenarios in this study

On the other hand, regarding BAU scenario, the immigrated ratio is 0% between 1998 and 2030. So, urban area is not change. Middle Density scenario is assumed to ratchet down urban area. In 2030, urban area attains 50% of present area. In turn, Middle Density scenario and High Density scenario are assumed to ratchet down urban area to 50% and 30%.

4. MODEL VALIDATION

Existing studies introduced a variety of model validations. And so, the model in this study was validated based on study of Wang, et al. (2008).Validated the proposed model, it was applied to simulate 2010, the results using the data between 1998 and 2030. The result values of GRDP per capita, population, and total number of vehicles were compared with the reported data, shown on Table 2.

Table 2: The results of model validation

Index [Unit]	Reported data	Model output	Error [%]
GRDP per capita [US$]	2,655	2,711	2.11
Population [million people]	1.768	1.835	3.79
Total number of vehicle	77,335	72,786	−5.88

As the results, the errors are less than 6%. This proposed model was mathematical to estimate a variety of values.

5. RESULTS

As a result, shown in Figure 7, this figure is indicated the accumulated VKT of 3 scenarios. Values of accumulated were BAU scenario: 2,358,000 [km], Middle Density scenario: 1,470,000 [km], and High Density scenario: 1,724,000 [km]. BAU scenario was about one and half times as value as High Density scenario because of accumulated VKT were had a huge effect on urban area. Also, Middle Density scenario was effective against accumulated VKT.

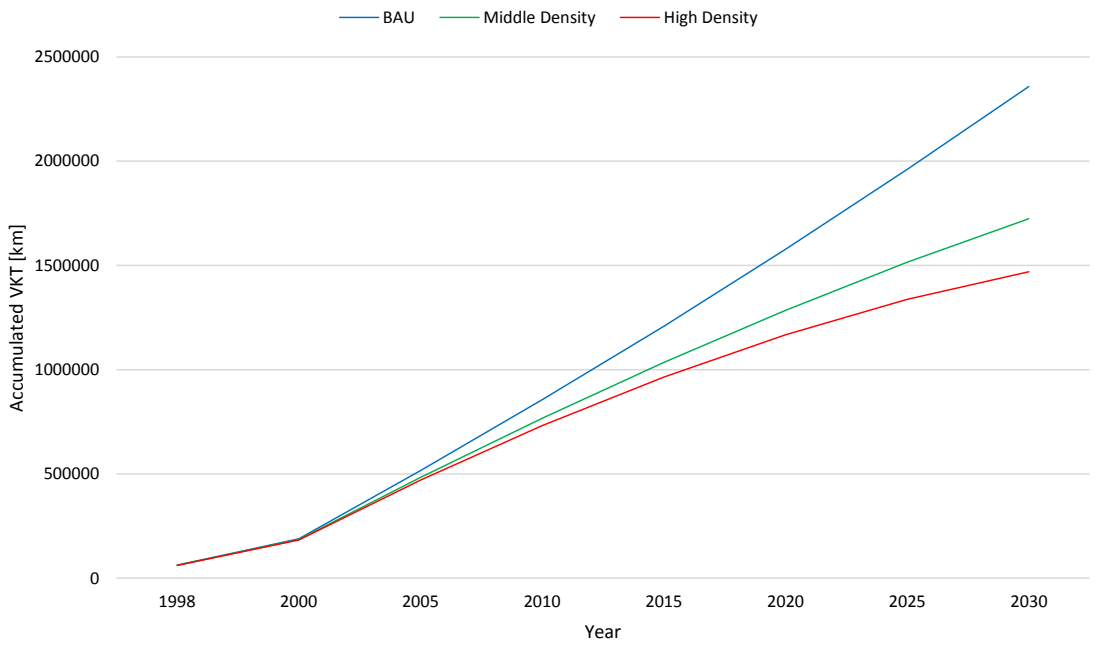

Figure 7: Accumulated VKT of 3 scenarios

On the other hand, shown in Figure 8 is indicated the CO_2 emission of 3 scenarios. Values of CO_2 emission were BAU scenario: 2,011 [million kg-CO_2], Middle Density scenario: 1,451 [million kg-CO_2], and High Density scenario: 1,244 [million kg-CO_2]. CO_2 emission of BAU scenario also was higher among the other scenarios. The reason like this result was related to VKT because of CO_2 emission is so high as to change of slope is big.

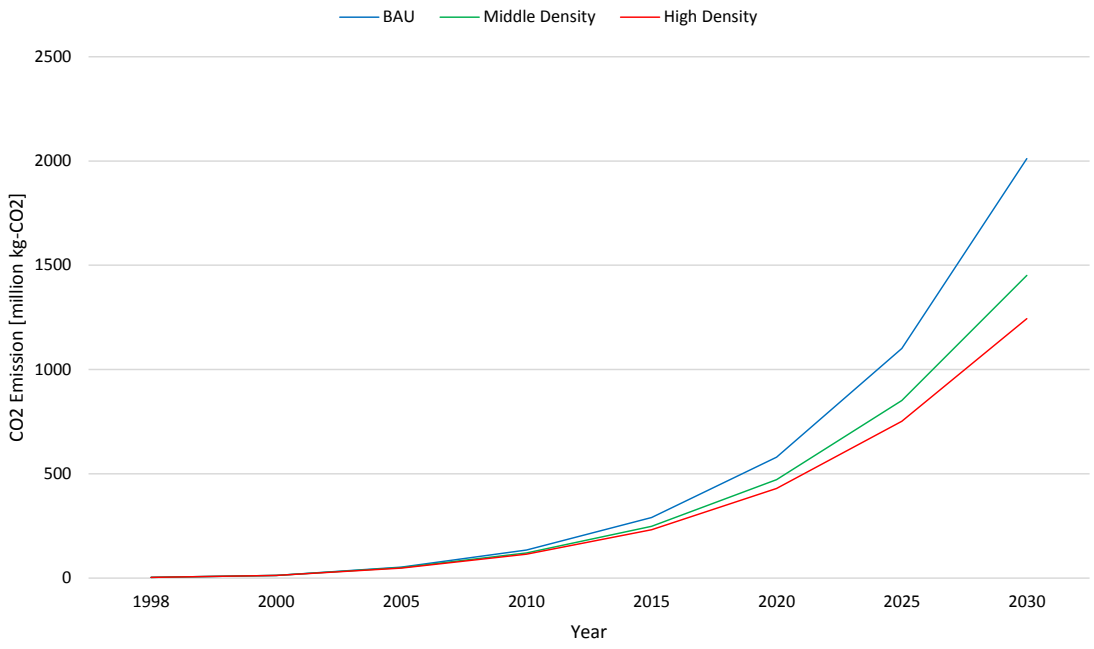

Figure 8: CO_2 emission of 3 scenarios

6. CONCLUSIONS

In this study, we could estimate the CO_2 emission reduction with the change of urban structure in Khon Kaen as a case of a developing country. It was found that the scenario implementing density growth of urban area could reduce 38.1% of CO_2 emissions, as compared with BAU scenario. However, CO_2 emission reduction was rather small if only single policy was applied in Khon Kaen.

For further study, we need to estimate CO_2 emission when it is implemented the comprehensive polices in which land use plan, rail or guide way transport, technical innovation, and energy consumption are included to realize a Low Carbon Society.

7. REFERENCES

M. C. Chen, et al. 2006. A System Dynamics Model of Sustainable Urban Development: Assessing Air Purification Policies at Taipei City. *Asian Pacific Planning Review Vol. 4, No. 1*.

J. Wang, et al. 2008. System Dynamics Model of Urban Transportation System and Its Application. *Journal of Transportation Systems Engineering and Information Technology Vol. 8, Issue 3, 83-89*.

J. A. Duran-Encalada, et al. 2009. System Dynamics Urban Sustainability Model for Puerto Aura in Puebla, Mexico. *Systemic Practice and Action Research 22, 77-99*.

Y. Y. Feng, et al. 2013. System Dynamics Modeling for Urban Energy Consumption and CO_2 Emissions: A Case Study of Beijing, China. *Ecological Modelling 252, 44-52*.

A. Stefano, et al. 2010. A System Dynamics Energy Model for a Sustainable Transportation System. *Proceedings of the 28th International Conference of the System Dynamics Society*.

J. Han, et al. 2008. A System Dynamics Model of CO_2 Mitigation in China's Inter-city Passenger Transport. *Transportation Research Part D 13, 298-305*.

M. D. Stepp, et al. 2009. Greenhouse Gas Mitigation Policies and the Transportation Sector: the Role of Feedback Effects on Policy Effectiveness. *Energy Policy 37, 2774-2787*.

G. Egilmez, et al. 2012. A Dynamic Modeling Approach to Highway Sustainability: Strategies to Reduce Overall Impact. *Transportation Research Part A 46, 1086-1096*.

Q. Shen, et al. 2009. A System Dynamics Model for the Sustainable Land Use Planning and Development. *Habitat International 33, 15-25.*

J. Han, et al. 2009. Application of an Integrated System Dynamics and Cellular Automata Model for Urban Growth Assessment: A Case Study of Shanghai, China. *Landscape and Urban Planning 91, 133-141*.

H. Kikuchi, et al. 2013. Possibility to Realize Low Carbon City in Medium-sized City of Asia: Case Study in Khon Kaen City, Thailand. *Proceedings of the Eastern Asia Society for Transportation Studies Vol. 9*.

A. Fukuda et al. 2013. Study on Estimation of VKT and Fuel Consumption in Khon Kaen City, Thailand. *Journal of the Eastern Asia Society for Transportation Studies Vol. 10, 113-130*.

I. Cameron, et al. 2004. Trends in Vehicle Kilometers of Travel in World Cities, 1960-1990: Underlying Drivers and Policy Responses. *Transport Policy 11, 287-298.*

Department of Provincial Administration, Ministry of Interior Thailand. Retrieved February, 2014, from http://www.dopa.go.th/.

Department of Land Transport, Ministry of Transport Thailand. Retrieved February, 2014, from http://www.moi.go.th/.

Trading Economics. Retrieved February, 2014, from http://www.tradingeconomics.com