Long term prediction system of urban CO_2 emission for Supporting the Reduction Policies. : Parts 3. Coupling of Multiple City Models

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Abstract

In order to develop a long-term vision for reduction of urban environmental loads, it is effective to make a long-term prediction simulator of environmental loads (energy consumption and CO_2 emissions amount) as an evaluation tool for environmental policies. Therefore, we made a simulator for Fukuoka city using system dynamics and evaluated the effect of some environmental measures as the first step of our research.
The purpose of this paper is to generalize the simulator to enable its application in various other cities as the second step of this research. So our model was conceived to be transferable. Incorporated previous research includes (Maruyama et al. 2016, Jieun et al. 2016) a study on CO_2 Emission Reduction Effects by ZEB/ZEH and Next-generation vehicles, and a Study on CO_2 Emission Reduction Effects by Subsidy. In this part, we made a new sector for coupling multiple cities, and considered the effect on surrounding cities from the environmental policies of big cities.
The paper is organized as follows: The first section gives the purpose for coupling multiple cities. The second section addresses development and the accuracy verification results of the coupling sector. It compares the calculation results of the simulator and actual values from 1990 to 2010. The simulation results had small errors, but it was able to capture actual values. In the third section we described the calculation results intended for Fukuoka City and Kasuga City by applying some policies, and compared each results. We compared CO_2 emissions applying each scenario from 2010 to 2050 and confirmed which scenario is more effective for reducing CO_2 emissions by 2050.

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Keywords
System Dynamics, General model, Scenario Studies, A Large-scale City, Multi-city Coupling

1. Introduction

The previous part indicated the base of the Habitat model and the development of the subsidy sector. In this paper, we describe the coupling of multiple city models by developing the coupling sector. We made a Kasuga model to couple onto a Fukuoka model, which has been previously developed. And we compared the calculation results of the coupling model to the actual value for accuracy verification. Then, through a calculation based on multiple scenarios, we will examine the impact of Coupled Model.

Figure 1 indicates the location of Fukuoka and Kasuga City in Japan. Fukuoka City is located in the western part of Fukuoka Prefecture, and the northern part of Kyushu. This city is the prefectural capital of Fukuoka Prefecture. It's area is 343.39 ㎢, population is 1.55 million people and population density is 4,510 people / ㎢. Fukuoka City's population is one of the top 5 in the city of Japan, and the largest in the Kyushu region.

Kasuga is a city located Midwest Fukuoka Prefecture. It is to the south-east of Fukuoka City, and it is a part of the Fukuoka metropolitan area. This city was developed as commuter town of Fukuoka City. Its area is 14.15 ㎢, its population is more than 100 thousand people, and its population density is 7,820 people / ㎢, the highest in Fukuoka Prefecture.

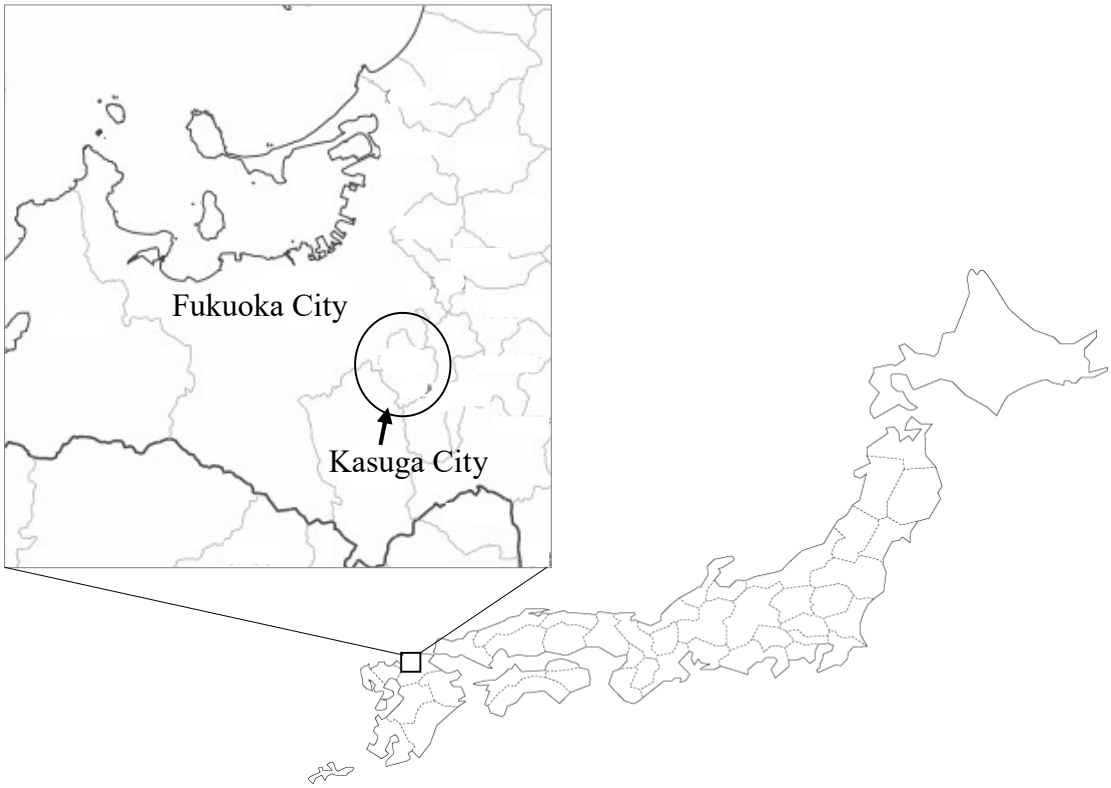

***Figure 1**. The location of Fukuoka City and Kasuga City in Japan*

2. Multiple city model

Over-concentration of population in large cities is progressing in currently Japan. The overcrowding of large-scale cities and population reduction in small- and medium-scale cities there is remarkable. Under these conditions, future prediction for the policy effects of large-scale cities, by consideration of the impact of surrounding cities which have different population and industrial structures from the large-scale city, enables policy planning support for more practical reduction of environmental load.

Moreover, regional classification is measured for each municipality. Therefore the current simulator creates models for each municipality, and the measure's range is also remains within municipalities. In actuality, the number of workers or traffic volume are closely related to surrounding cities, and it is also considered that the range of policy extends to surrounding cities.

Based on the above background, this study aims to develop a coupling method of multiple city modeling.

3. Coupling sector

Figure 2 indicates a conceptual diagram of a coupling sector. Table 1 shows a description of the English abbreviations in Figure 2. The calculation item in the coupling sector is calculated by explanatory variables in both urban models. As the main item that affected both cities, we set population, companies, and traffic volume to calculated items in the coupling sector. According to the variables in the simulator, we set each to population movement, start of construction for business buildings, and passenger transportation volume.

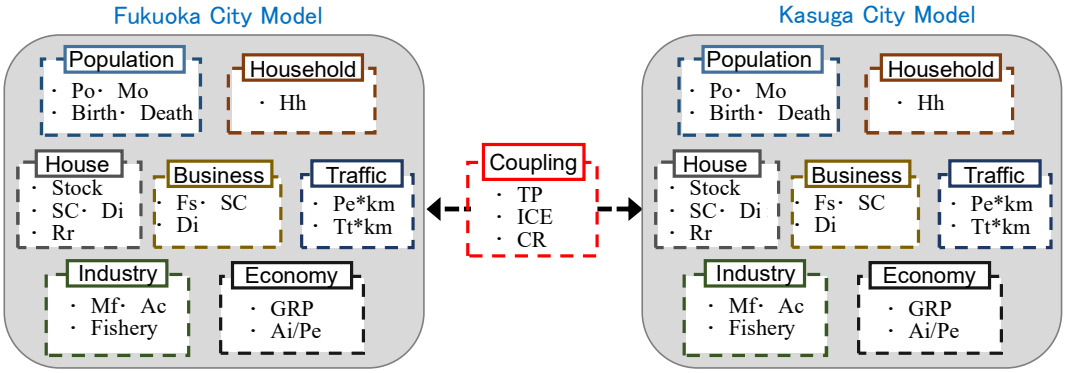

***Figure 2**. A conceptual diagram of a coupling sector*

***Table 1.** English Abbreviations in Figure 2*

Abbreviation	Original Word	Abbreviation	Original Word
Ac	Agriculture	Mf	Manufacture
Ai	Average income	Mo	Moving
CR	Construction Ratio	Pe	People
Di	Dismantling	Po	Population
Fs	Floor Space	Rr	Residential rate
GRP	Gross Regional Product	SC	Start of Construction
Hh	Household	TP	Total Population
ICE	Inter-city Commuting Employees	Tt	Transport Tonnage

3.1 Population moving

Figure 3 indicates the conventional calculation flow of the population moving. The simulator can calculated the negative value (moving-out is exceeded moving-in) of the moving by this calculation method. But this method has the problem that fluctuations in the base year ratio is small (Table 2), so the impact of the error is large. Therefore, in order to stabilize the calculations, we divided the population moving into the moving-in and moving-out, and further divided them into the target cities moving and other cities moving. Figure 4 indicates the improved calculation flow of the population moving. We set the total population moving from a difference of total moving-in and total moving-out.

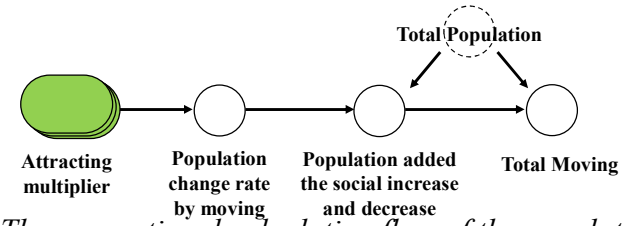

***Figure 3**. The conventional calculation flow of the population moving*

***Table 2.** The base year ratio of Population change rate by moving*

	Fukuoka City	Kasuga City
1990	1.0000	1.0000
1991	0.9994	0.9986
1992	0.9988	0.9972
1993	0.9988	0.9949
1994	0.9991	0.9927
1995	0.9997	0.9908
1996	1.0003	0.9888
1997	1.0011	0.9872
1998	1.0015	0.9854
1999	1.0019	0.9838
2000	1.0020	0.9822
2001	1.0021	0.9809
2002	1.0020	0.9795
2003	1.0023	0.9797
2004	1.0025	0.9798
2005	1.0024	0.9798
2006	1.0026	0.9799
2007	1.0024	0.9800
2008	1.0022	0.9805
2009	1.0021	0.9809
2010		
Max	1.0026	1.0000
Min	0.9988	0.9795

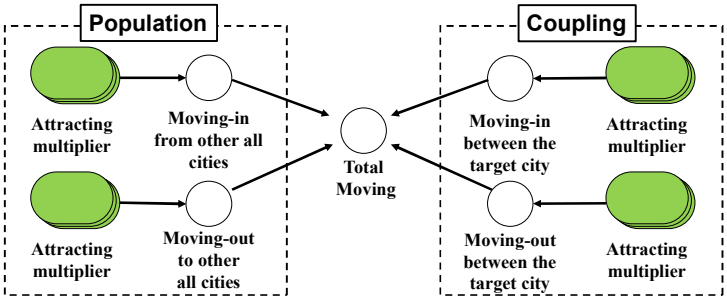

***Figure 4**. The improved calculation flow of the population moving*

3.2 Inter-city commuting employees

We assumed that all the inter-city commuting employees of the surrounding cities (such as Kasuga City) commute to the central city (such as Fukuoka City). And we ignored the proportion of commuters from Fukuoka City to Kasuga city because we consider that their number is very small. We set inter-city employees values from the difference between the two statistical data sets. One is employee values from the statistical survey whose target is the households in the city, the other statistical survey's target is companies in the city. Figure 5 indicates the calculation flow of inter-city commuter passenger volume. The coupling sector calculates inter-city commuter passenger volume; the conventional passenger sector calculates other all passenger volume.

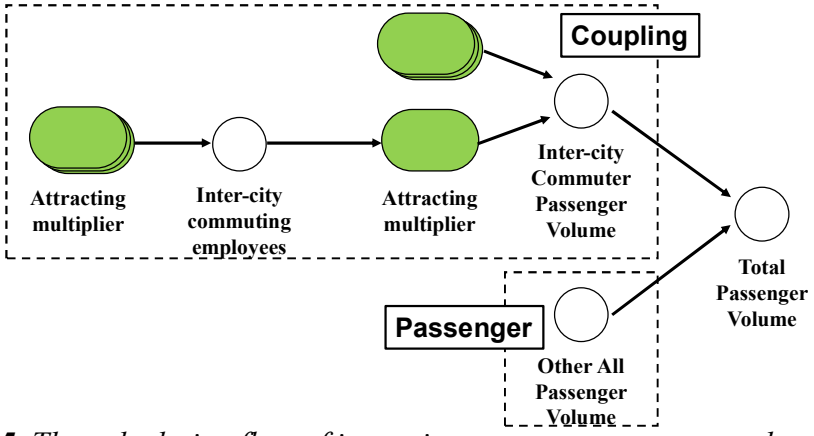

***Figure 5**. The calculation flow of inter-city commuter passenger volume*

3.3 Start of construction for business building

We regarded the two cities' total initiated construction projects for office floor, hospital floors, wooden floors and other floors as each total demand in each year. And we calculated the construction rate for each business of Fukuoka City and Kasuga City from the attracting multiplier in the coupling sector. Figure 6 indicates the improved calculation flow of construction floor space. The improved model calculates the total construction floor space for each business in each city from total construction demand and the construction ratio for each city in the coupling sector.

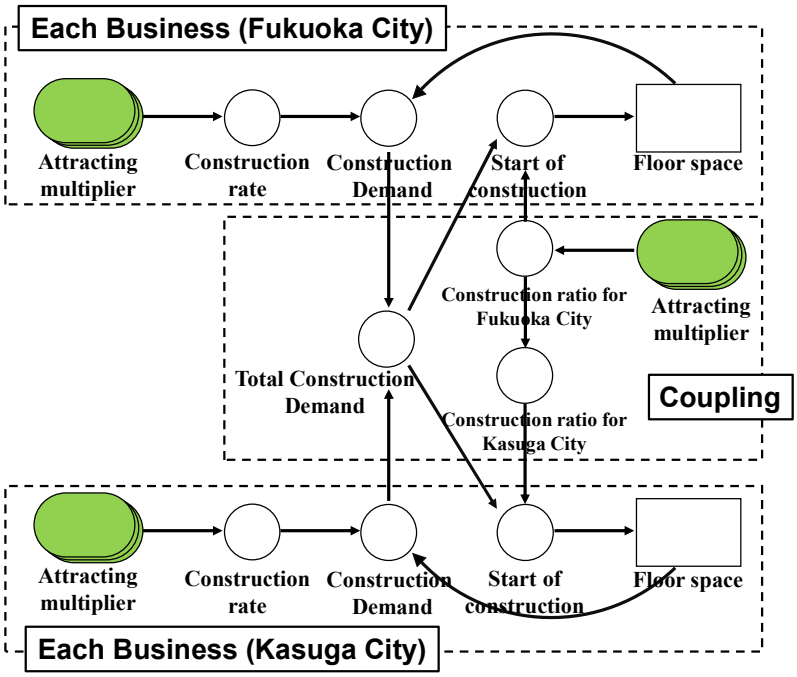

***Figure 6**. The improved calculation flow of construction floor space*

4. Accuracy verification

We compared the calculation results in the coupling model to the actual value for accuracy verification. Figure 7-12 indicates a comparison of the improved or added variable between the calculated results and the actual value. The calculation value of

inter-city commuter passenger volume around 2000 is less than the actual value, but almost all of the calculation results capture the transition of the actual value.

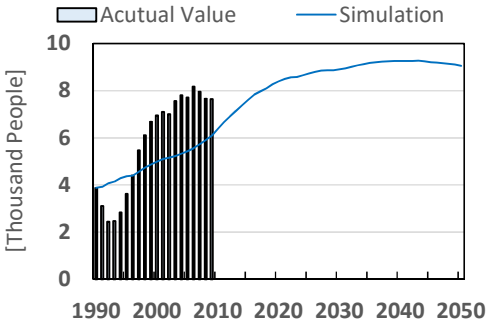

***Figure 7**. Moving (Fukuoka City)*

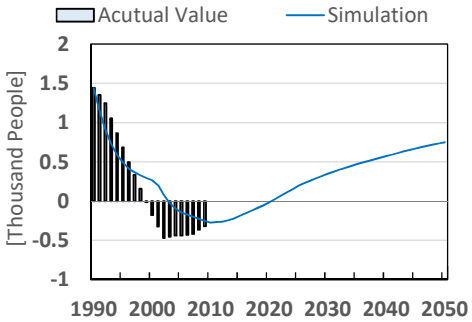

***Figure 8**. Moving (Kasuga City)*

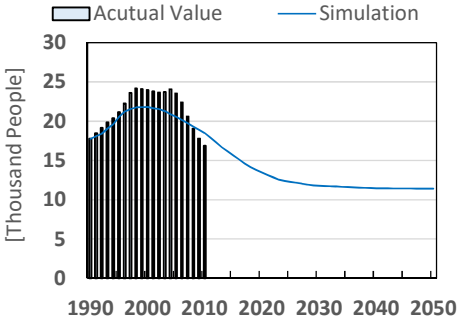

***Figure 9**. Inter-city commuting employees*

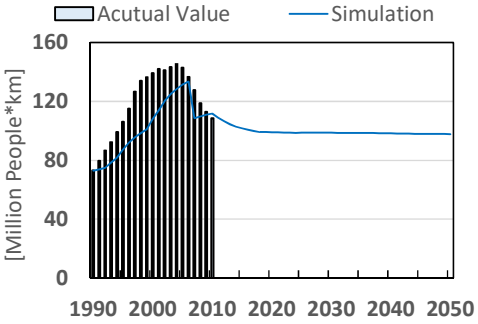

***Figure 10**. Inter-city commuter passenger volume*

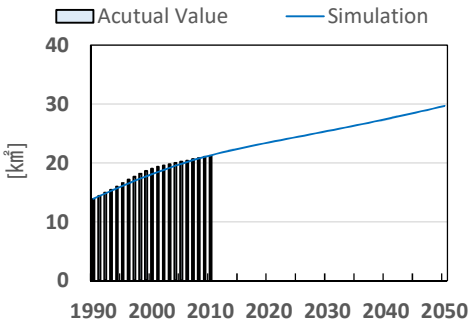

***Figure 11**. Floor Space (Fukuoka City)*

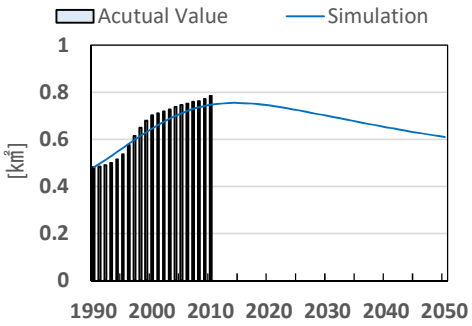

***Figure 12**. Floor Space (Kasuga City)*

5. Discussion of the Scenario

The effect of the scenario up to 2050 was discussed using the coupling model. Table 3 indicates a summary of the examination items.

***Table 3.** A* summary of the examination items.

Scenario	Summary
BAU Scenario	Remained at status quo
Compact City Scenario	Emigrate inter-city worker in Kasuga City to Fukuoka City from 2010 to make it 0 after 2030. And suppress the migrants to Kasuga City from Fukuoka City.
Commuter Town Scenario	Increase the moving from Fukuoka City of 20% every year,and pay the subsidy for the housing construction in Kasuga City.

5.1 Compact City Scenario

In order to revitalize the central city and suppress the expansion of urban land use to the outskirts, we propose to improve the workplace living proximity and prevent the population outflow from the Fukuoka City. In particular, we move inter-city workers in Kasuga City to Fukuoka City from 2010 to make it 0 after 2030, and suppress migrants to Kasuga City from Fukuoka City by 20% every year.

Figure 13 indicates a comparison of each sector's CO_2 emissions between BAU Scenario and Compact City Scenario from 2010 to 2050. And Figure 14-15 indicate a comparison of each sector's CO_2 emissions between BAU Scenario and Compact City Scenario in 2050. CO_2 emissions of Compact City Scenario in 2050 was greater than that of BAU Scenario. The reason is that Fukuoka City's activity becomes active as a result of the population being concentrated in Fukuoka City, and CO_2 emissions for Fukuoka City exceeded the reduction of CO_2 emissions for inter-city traffic and Kasuga City's activity.

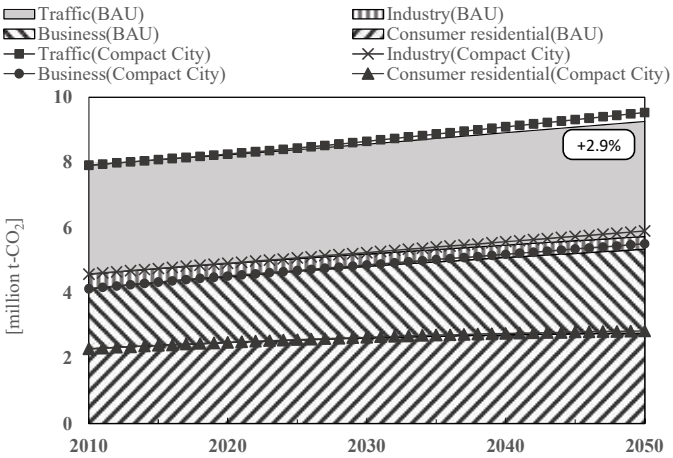

***Figure 13**. Compact City Scenario*

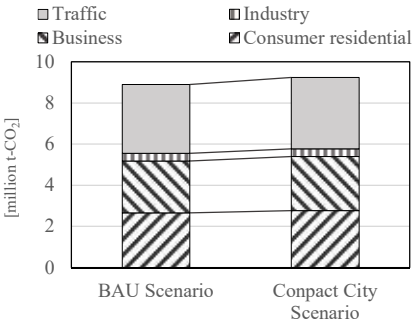

***Figure 14**. Fukuoka City(2050)*

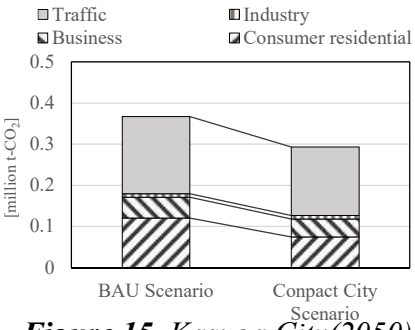

***Figure 15**. Kasuga City(2050)*

5.2 Commuter Town Scenario

In this scenario, we promote the construction of detached houses in Kasuga City, and increase the immigrants from Fukuoka after 2010 to encourage separation between living space and workplace. In particular, we increase the moving from Fukuoka City by 1.5 times, and pay a subsidy for housing construction in Kasuga City.

Figure 16 indicates a comparison of each sector's CO_2 emissions between BAU Scenario and Commuter Town Scenario from 2010 to 2050. And Figure 17-18 indicate a comparison of each sector CO_2 emissions between BAU Scenario and Commuter Town Scenario in 2050. CO_2 emissions of Commuter Town Scenario in 2050 were less than that of BAU Scenario. The reason is that this scenario reduced the Fukuoka City's activity, and the reduction of CO_2 emissions for Fukuoka City is

greater than the increase of CO_2 emissions for inter-city traffic and Kasuga City's activity.

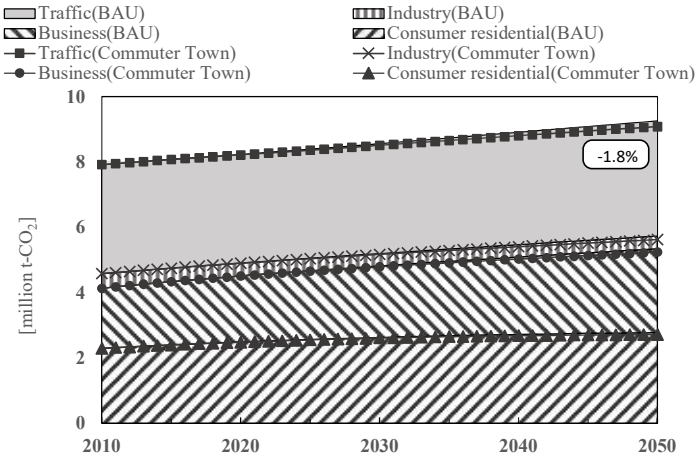

***Figure 16**. Commuter Town Scenario*

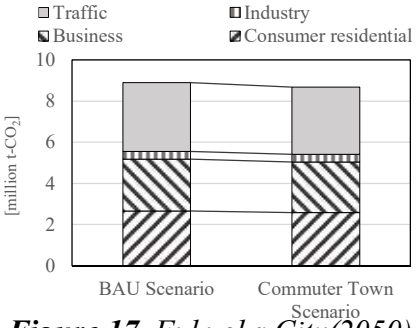

***Figure 17**. Fukuoka City(2050)*

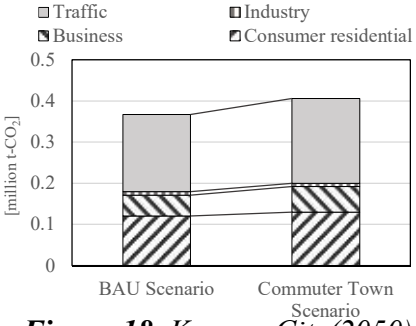

***Figure 18**. Kasuga City(2050)*

From discussions of the two scenarios, we found that it is more effective to reduce the environmental load between Fukuoka City and Kasuga City by dispersion of the population to Kasuga City than concentration of the population in Fukuoka City.

Conclusion

In this report, we developed a new sector for coupling of multiple cities and did actual verification for the new sector. Then, we examined scenarios by using a coupling model of Kasuga City and Fukuoka City.

As a result, it was confirmed that dispersion of the population is effective in the reduction of CO_2 emissions in Kasuga and Fukuoka City. Since we studied only two cities in this report, broad-based future prediction requires further consideration by adding the other cities surrounding Fukuoka City.

Acknowledgment

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