Study on Impact Evaluation of Introducing Policies to Realize Urban Consolidation by Using MARS: Case Study of Niigata, Japan

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Abstract: *Even low carbon society is one of solution to tackle with global warming problem, it is very difficult to realize such society because we have to employ all of policy measures in order to reduce huge amount of CO_2 emission. Thus, efficient roadmaps which show timing and combination of policy measures should be established to realize low carbon society. This paper attempts to set up such roadmaps for Niigata city and its vicinities in Japan by using Metropolitan Activity Relocation Simulator, or so-called MARS in which land use and transport interactions was basically simulated by using the system dynamic model. On the simulation, timing and combination to implement land use and transport-related policies such as new public transport and land use restricted on CO_2 emission was tested. These obtained information are can help the city officers to achieve the appropriate policy strategies so as to realize low carbon society.*

Keywords: Urban Consolidation, MARS, Transport Sub-Model, Land Use Sub-Model, CO_2 Emission, Low Carbon Society, Niigata City, Impact Evaluation

1. Introduction

Global warming has become the most talked-about environmental issue today. Obviously, it causes climate change which lead to increase the average temperature of Earth's atmosphere and ocean level. As known, carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. The main human activity that emit CO_2 is the combustion of fossil fuels for energy and transportation, although certain industrial processes and land use changes also emit CO_2[1]. The international community has recognized the need to reduce greenhouse gas (GHG) emissions by 50% by 2050 in order to keep global mean temperature change within 2 degrees centigrade compared to pre-industrial times (National Institute for Environmental Studies, 2011). Thus, it is extremely important to create strategic roadmaps relating to land use and transportation fields to realize low carbon society because they produces a large proportion of greenhouse gases. However, it is really difficult to measure which strategic roadmaps are efficient to employ.

Obviously, land use and transportation have a close relationship as two sides of the same coin. Changes in land use due to the land use control affect the transportation demand and behavior as new public transportation implemented also affect land use patterns. However, this relationship mostly explains and determines in term of linear behavioral approach. Recently, System Dynamics (SD) model, which is determined by the non-linear behavioral, has become popular approach for understanding dynamic urban and transportation interaction. Additionally, SD model is a methodology and mathematical modeling, which was firstly introduced by Prof. Jay Forrester of MIT during the mid-1950, for better understanding complex problems and issues via causal loop diagrams (stocks and flows). For example, Shen and others (2009) applied a system dynamics model for the sustainable land use and urban development in Hong Kong. Likewise, Xu and Coors (2012) attempted to combine System Dynamics model, GIS, 3D visualization in sustainability assessment of urban residential development for

[1] United States Environmental Protection Agency
http://www.epa.gov/climatechange/ghgemissions/gases/co2.html

Stuttgart Region of the state of Baden-Württemberg in Southern Germany.

Metropolitan Activity Relocation Simulator (MARS) model is an approach for testing the outcomes of development policy scenarios and make forecasts based on the principles of SD and synergetic. Several previous literature applied the MARS model in determining the relationship between land use and transportation. For example, Pfaffenbichler (2003) used the MARS model to calibrating the dynamics land use and transportation interaction modeling for the city of Vienna. The outcomes could explain what it would be after implementing transport project planned and under construction. However, integrating the MARS model with CO_2 emission estimation so as to realize low carbon society is still not investigated in any previous literatures. Thus, this paper attempts to integrate the MARS model with CO_2 emission estimation after implementing strategy roadmaps in relation to realize low carbon society. The Niigata city and its vicinities in Japan are chosen as case study. As know, Japan is one of the countries throughout the world that has an efficient public transportation network. However, it was found that private car is the primary mode of transportation in Niigata city and adjacent areas. This reason might be the main cause of the traffic congestion especially in peak hours and also emits pollution. Therefore, Bus Rapid Transit (BRT) together with Transit Oriented Development (TOD) policies is being introduced to alleviate these urban issues and reduce the air pollution. The obtained information from the MARS model can help the city officers to achieve the appropriate policy strategies. Furthermore, the MARS model was applied to several cities being located in Europe including Edinburgh-UK, Helsinki-FIN, Leeds-UK, Madrid-ESP, Oslo-NOR, Stockholm-SWD and Vienna-AUS. However, it is less attention in Asia cities. Therefore, this is a minor reason to apply this model to Niigata urban areas.

The rest of this paper is organized as follows. Section 2, an overview of previous land use and transport model MARS as well as the structure of the MARS model will be presented. Context of case study, various data used for the analysis will be presented in section 3. Section 4 explains the policy scenarios and the obtained results. Finally comes the conclusion.

2. Literature Review

2.1 Land Use and Transport Model

More than a half century, substantial attempts have been made to empirically investigate the relationship between land use and transportation. The first attempt to implement the urban land use and transport feedback cycle based on the law of gravity model was presented by Lowry (1964). Recently, land use and transport integrated (LUTI) model has been implementing in a number of cities in Europe and Americas, but it is still less attention to apply in Asian cities. Each land use and transport integrated model is common and/or different in the model structure utilized, the types of sub-model, and speed of change. Some of these models are summarized as follows. The California Urban Futures Model (CUFM) combined separate components including land use, workplace, housing, employment and population based on bid-choice theory and random utility theory (Landis, 1994; Landis and Zhang, 1998). Likewise, the DELTA land use model was developed by David Simmonds Consultancy (Simmonds, 1999).

MEPLAN software package was created by Marcial Echenique and Partners Ltd of Cambridge, England (Abraham, 1998; Echenique and others, 1969; Hunt and Echenique, 1993). In addition, Nishiura and Matsuyuki (2005) assessed a wide range of alternative polices and scenarios for Tama urban monorail by using MEPLAN model. Some results showed that the number of passengers on the lines connecting the areas further west than Tachikawa city will dramatically decrease and the passenger will increase 20 percent if the monorail is extended in future scenarios. UrbanSim based on the choices of households, businesses, land owners and developers, interacting in urban real estate markets and with the option to be connected to a transportation simulations one of the most advanced LUTI model (Waddell, 2002). UrbanSim[2]was initially designed by Paul Waddell in the mid1990's, and implemented as a prototype in Oregon in 1998. Kakaraparthi and Kockelman (2011) described the modeling of year 2030 land use patterns of the Austin, Texas region using UrbanSim at fine spatial resolution (typically 150 m x 150 m grid cells) after implementing some policy scenarios such as added transport-cost-sensitivity scenarios (TCS), expanded highway capacity scenario (EXPAN) and so on. Furthermore, UrbanSim was applied to model land use and transportation interaction in the canton of Zurich, as one of three case studies of the SustainCity project (Schirmer and others, 2011). Other the most advanced European LUTI models are IRPUD (Wegener, 1998), MUSSA (Martinez, 1996) and MARS (Pfaffenbichler, 2003; Pfaffenbichler, 2008; Pfaffenbichler and others, 2010).

2.2 Structure of the MARS Model

Metropolitan Activity Relocation Simulator (MARS) model is an approach for better understanding land use and transport interaction based on the principles of System Dynamics (SD) and synergetic.

System Dynamics (SD)[3] model, a computer-aided approach to policy analysis and design, which is determined based on non-linear, ordinary differential (or integral) equations. The feedback concept obtained from diagrams of causal loop is a central role of the system dynamics approach. The causal loop diagram is a simple map that reveals the structure of a system using stock and flows for each internal loop at each iteration (Morecroft, 1982). Recently, the SD model has become more popular to apply for understanding the complex issues in determining land use and transport interactions after implementing policies such as new public transport and land use restricted on CO_2 emission (Feng and others, 2013; Fiorello and others, 2010; Han and Hayashi, 2008; Landis and Zhang, 1998; Pfaffenbichler and others, 2010; Wang and others, 2007; Wang and others, 2008). For example, Haller and others (2008) attempted to model domestic migration on national level in Austria. Fiorello and others (2010) applied the SD model for the strategic assessment of policy scenarios at the European level.

As the stated, the MARS model is a one of dynamic Land Use and Transport Integrated (LUTI) model. The present version of the MARS model is implemented in Vensim®, a System Dynamics programming environment. The MARS model includes a transport model which simulates the travel behavior of the population related to their housing and

[2] http://www.urbansim.org/
[3] http://www.systemdynamics.org/

workplace location, a housing development model, a household location choice model, a workplace development model, a workplace location choice model, as well as a fuel consumption and emission model as illustrated in Figure 1. All these models are interconnected with each other.

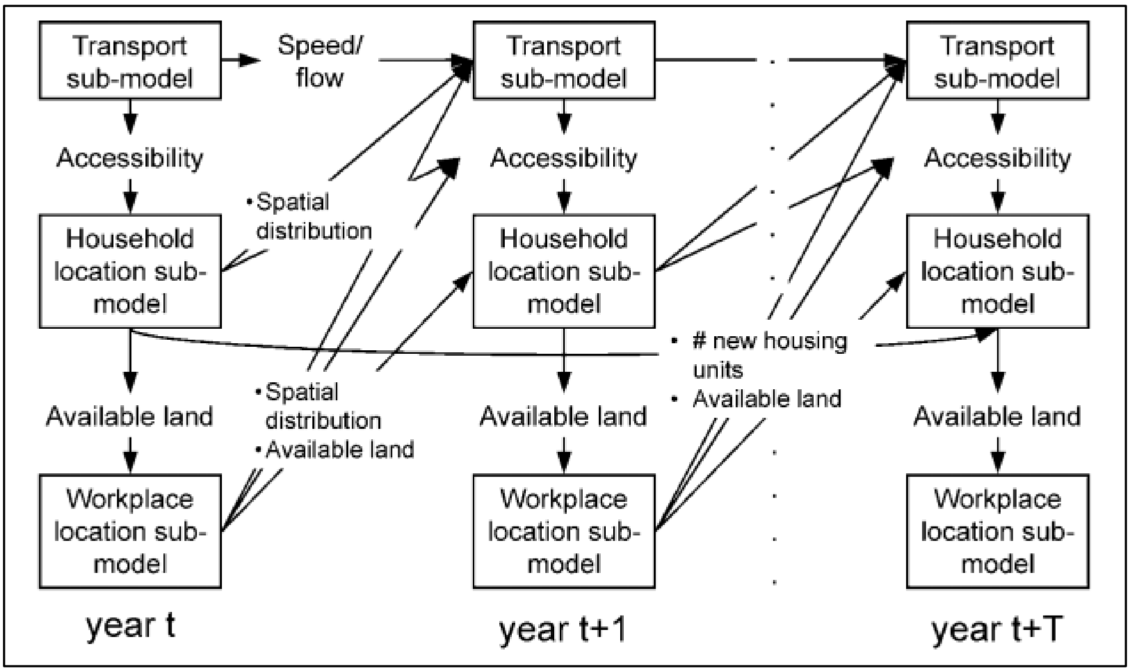


Figure 1 Structure of the MARS model (Pfaffenbichler, 2003)

In Figure 1, the MARS model starts with the calculation of *transport sub-model*. Accessibility indicators are input into the *household location sub-model* and the available land is calculated. Then, the value of available land is used for the *workplace location sub-model* computation. After finished year *t*, speed flow from the *transport sub-model* and spatial distribution from the *household location sub-model* are passed to the *transport sub-model* in year *t+1* while new residential development is passed to the *household location sub-model*. Then, spatial distribution and available land obtained by the *workplace location sub-model* are passed to the *transport sub-model* and the *household location sub-model*. All of sub-model are run iteratively over a period of time until a time lagged iteration *t+T*.

2.2.1 Transport Sub-Model

Transport sub-model in the MARS model simulates passenger transport and comprises trip generation, trip distribution and mode choice which is calculated based on a gravity (entropy-maximizing) type model. Modes in the MARS model mean slow, car, public transport (rail and bus). In addition, all non-motorized mode such as walking, cycling and so on are assigned to slow mode. Furthermore, trips are estimated each purposes of work (HWH) and others (HOH).

As the stated, the MARS model is an approach for better understanding land use and transport interaction based on the principles of the SD model via casual loop diagram.

Thus, transport sub-model for the factors that affect the number of commute trips taken by car from zone to other using casual loop diagram can be illustrated as shown in Figure 2.

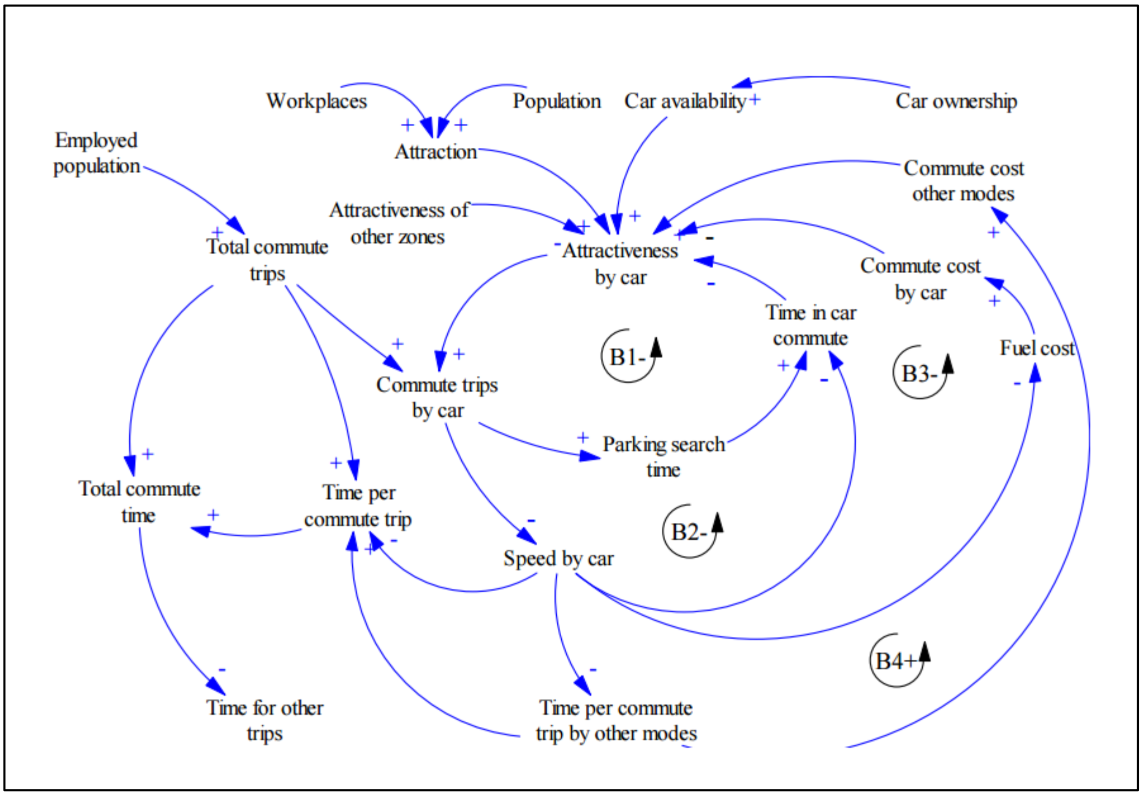


Figure 2 Sample of Causal Loop Diagram for Transport Sub-Model in MARS: Commute trips taken by car (Pfaffenbichler and others, 2010)

From the Figure 2, starting with the balancing feedback Loop B1, commute trips by car increase as the attractiveness by car increases, which lead to increase the searching time for parking which then decrease the attractiveness to use private car. This sequence is the balancing nature of loop. Loop B2 attempts to balance the effect of congestion, i.e., travel speed and travel time. While Loop B3 explains the impact of travel speed on fuel consumption, i.e., as speed increases, fuel consumption is decreased.

2.2.2 Land Use Sub-Model

The land use sub-model simulates the development of new housing and workplace developments within the different zones. While, the model for the development of new housing (residential model) is split into two sub-model: supply side and demand side, workplace model is developed based on the market force within each area such as economic growth rate. The causal loop diagram for residential development is illustrated as shown in Figure 3.

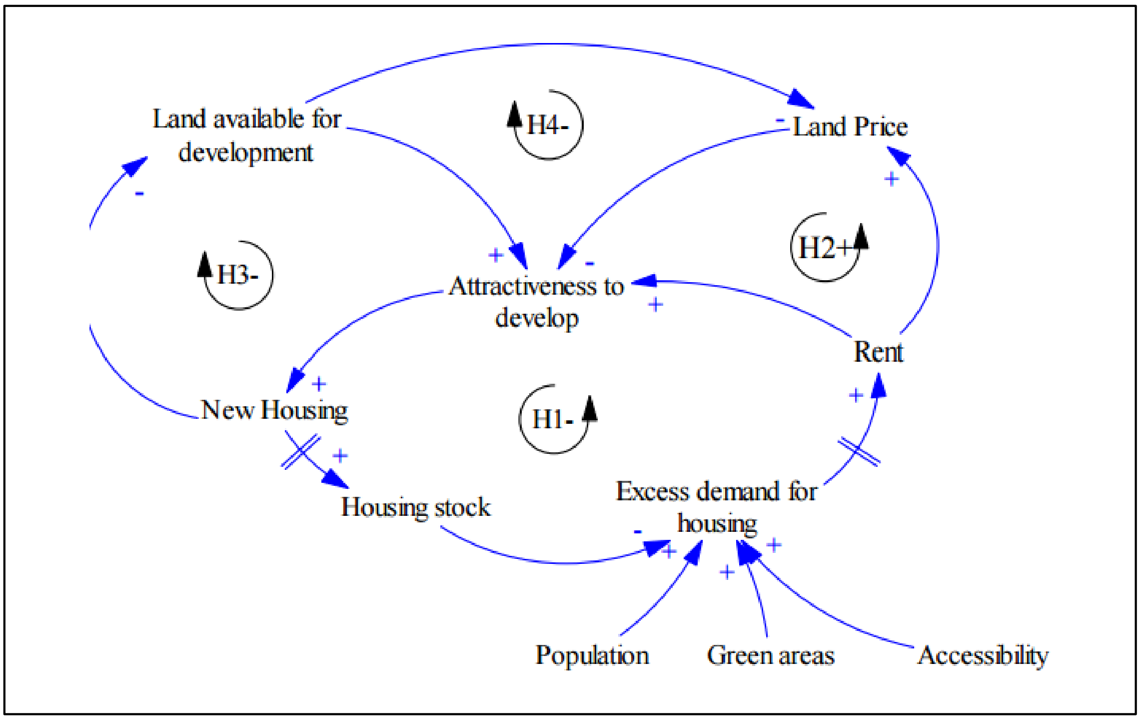


Figure 3 Sample of Causal Loop Diagram for Land Use Sub-Model in MARS: Residential model (Pfaffenbichler and others, 2010)

From the Figure 3, starting with balancing feedback Loop H1 which shows that the attractiveness to developers to develop residence in a given zone is determined by housing rent which can be achieved. The level of rent is based on the demand which lead to increase housing development until the demand point, meaning that feedback loop is balanced. Loop H2, after demand of new housing reduces which absolutely in turn to decreases land price and housing rent. Thus, this is attractiveness to developer to develop new housing, again. This sequence is the balancing nature of Loop H2. As a result of Loop H1 and H2, the land available is reduced which in turn to reduce the attractiveness to the developer in Loop H3. Loop H4 extends H3 to represent the effect of land availability on land price. Finally population, amount of green space and accessibility to activities from that zone drive the demand for housing.

2.2.3 Relationships among Variables in Transport and Land Use Sub-Models

Figure 4 shows the relationships among variables in two sub-models i.e., transport sub-model and land use sub-model. *Travel Time per Capita* and *Trip Generated Rate (HWH)* are constant values that were inputted into the MARS model as the exogenous variables. Furthermore, transport sub-model and land use sub-model are linked by *Accessibility* and *Number of Residents*. While, *Travel Cost (HWH and HOH)* and *Travel Time (HWH and HOH)* effected directly to transport sub-model, *Accessibility*, *Attractiveness*, and *House Rent or Mortgage* effected directly to land use sub-model. In addition, thick-round frames are variables by using the data per zone inputted to the MARS model.

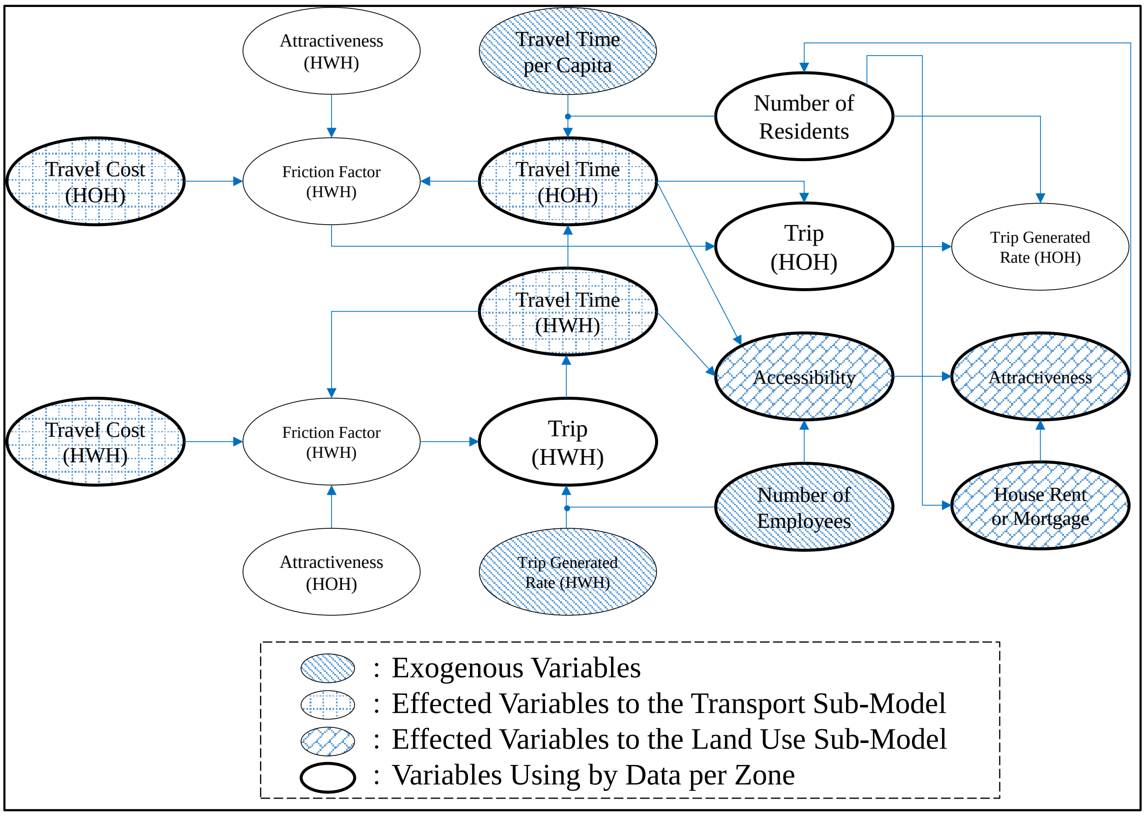


Figure 4 Some Variables in Transport and Land Use Sub-Models

3. Case Study: Niigata City and its Vicinities

The study areas are Niigata city and its vicinities as presented in Figure 5. Niigata city is the capital of Niigata Prefecture in Japan which is located on the northwest coast of Honshu. The vicinities consist of Shibata city, Agano city, Gosen city, Sanjyo city, and Tsubame city. They covers an area of 7,761.5 km^2 and had population of about 1.3 million in 2002 with a population density of 2,070.6 per km^2 (Statistical Office of Niigata City). The average car ownership was 640 cars/1,000 persons and average daily person trip was 2.65 trips/person.

In Figure 5, the study areas are divided into 35 zones by using GIS. Eighteen zones of them have stations of JR lines. Such networks unavoidably generate huge amount of travel demand which are mostly made by long distance trips by private cars.

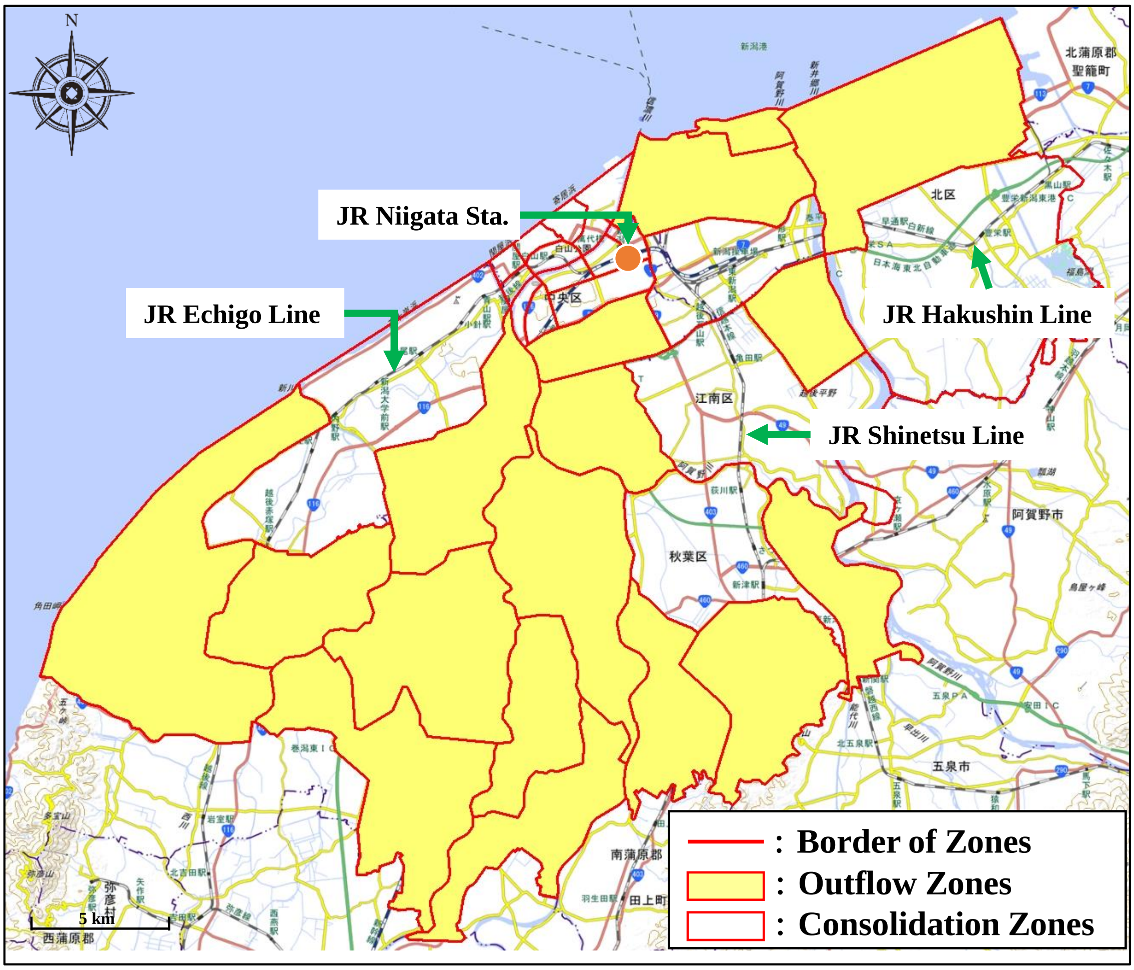


Figure 5 Study Areas

Figure 6 shows the relationship between the number of population and number of vehicle in Niigata city and it vicinities. It found that the population was nearly 1.31 million people and the number of vehicle were nearly 1.29 million cars, meaning that they owned private car nearly 1 car/person in 2002. Year by year, the number of population is still decreasing, the number of vehicle are gradually increasing. For example, the car ownership in 2004 and 2013 were 1 car/person and 1.03 car/person, respectively. This can be claimed that the transportation in Niigata and its vicinities is currently based on road and expressway network which in turn to be congested, in particular peak hour period. Absolutely, this situation is affect to the CO_2 emission which is one of the greenhouse gases that directly impact to the increasing of temperature.

Thus, this paper attempts to set up such road map for Niigata city and its vicinities in Japan by using Metropolitan Activity Relocation Simulator, or so-called MARS in which land use and transport interactions was basically simulated by using the system dynamic model in order to realize low carbon society which is one of solution to tackle with global warming problem,

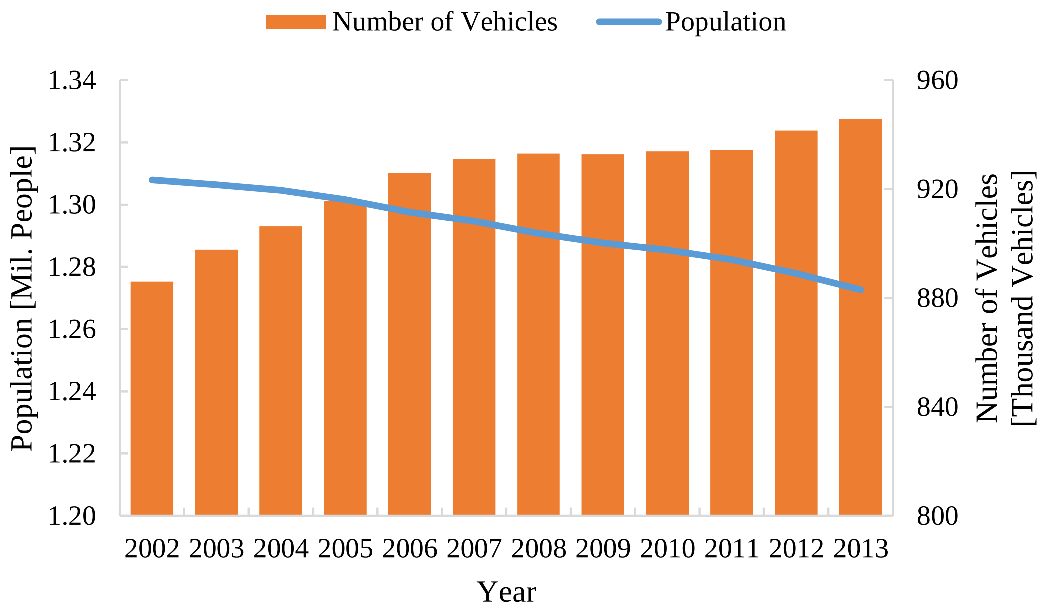


Figure 6 Number of Population and Vehicle in Niigata City and its Vicinities

4. Policy Scenarios and Simulation Results

4.1 The Policy Scenarios

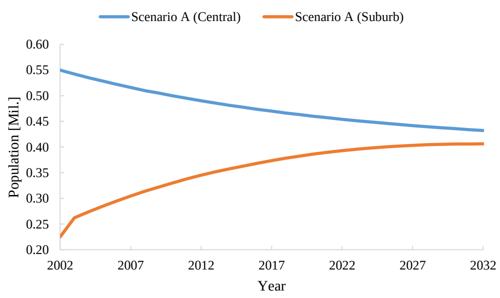
This section presents the estimated results from the MARS model after introducing 5 policy scenarios to Niigata city and its vicinities including Shibata city, Agano city, Gosen city, Sanjyo city, and Tsubame city. Five policy scenarios are briefly described as below. Conceptually, each scenario represents different expectations about vehicle kilometer travel (VKT) and CO_2 emission reduction as a result of VKT decreasing.

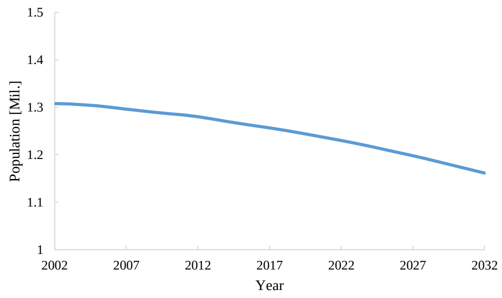
Scenario A represents business as usual baseline case, which assumes that future land use and transport development trends follow those other of the past and no changes in policies will take place. Additionally, the data in the year 2002 was represented as a base case in this study. Scenario B represents the urban consolidation policy scenario in the year 2002. This policy aims to reduce the VKT which is related to CO_2 emission reduction. As explained, people living in Niigata city and its vicinities always travel by cars because their housing is quite far from the JR rail transit networks. In order to reduce the VKT, three percent of people living in each zone without JR rail transit networks are consolidated to zones along JR lines, instead. However, there are no change in public transport networks and head way.

Scenario C and Scenario D are the same conditions as Scenario B, but the urban consolidation policy scenario was launched in the year 2012 and year 2022, respectively. While, scenario E implemented the urban consolidation policy scenario in the year 2002 integrating with headway (rail) improvement. Basically, the survey data presents that 15 min and 20 min are the headway during peak hour and off peak, respectively. Thus, in scenario E, the headway is changed from 15 min. to 7.5 min. for peak hour period and from 20 min. to 10 min. for off peak period.

4.2 Results of Population and VKT Estimation

This section presents the simulated results of population and vehicle kilometer travel (VKT) from the MARS model. Firstly, Figure 7 to Figure 11 show the number of estimated population from each scenario. In Scenario A, it found that population in central area tends to decrease as population in suburban area increases as shown in Figure 7 (a). This reason is because the high density in the central area that push people to suburban area. However, the total population in whole area of Niigata city and its vicinities is still decreasing as shown in Figure 7 (b). Furthermore, the estimated VKT tends to increase until the year 2020 and then slightly decreases as illustrated in Figure 8. This situation might be related to the population decreasing.





(a) Central area and suburban (b) Whole area

Figure 7 Population in Scenario A

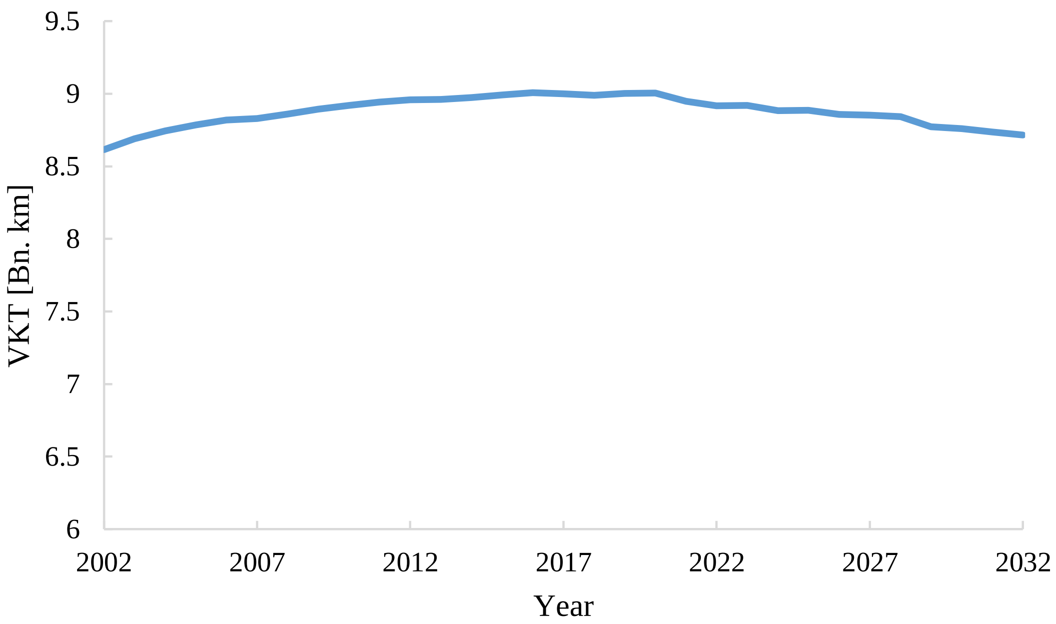


Figure 8 VKT of Scenario A

After policy scenario B, C, D, and E were implemented, the estimated population (central area and suburban) are likely to increase only the year that the urban consolidation employed as illustrated in Figure 9 to Figure 11.

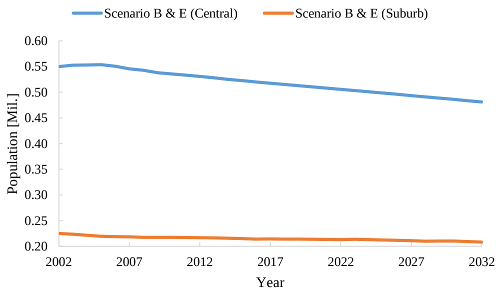


Figure 9 Population in Scenario B and E

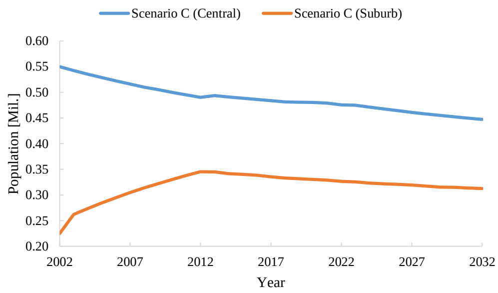


Figure 10 Population in Scenario C

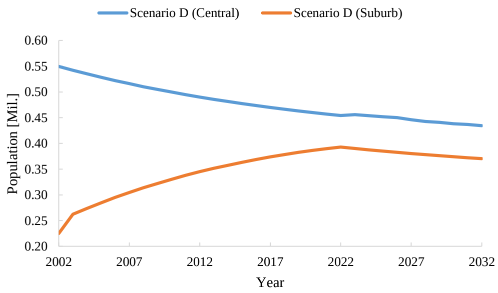


Figure 11 Population in Scenario D

On the other hand, after three percent of people living in each zone without JR rail transit network was consolidated to zones along JR lines, VKT tends to decrease at the year that the policy scenario was introduced, i.e., the year 2002, 2012 and 2022 as presented in Figure 12. This reason is because three percentage of people that were push into JR lines zones might be shifted their modes from private car to public transit such as rail. Furthermore, in scenario E, the headway was improved from 15 min. to 7.5 min. during peak hour period and from 20 min. to 10 min. during off peak period. Comparing between the VKT result from scenario B and scenario E, the result clearly showed that VKT obtained from scenario E is much less than scenario B. Obviously, the headway improvement policy attracts the passenger to shift their travel behavior to use them more.

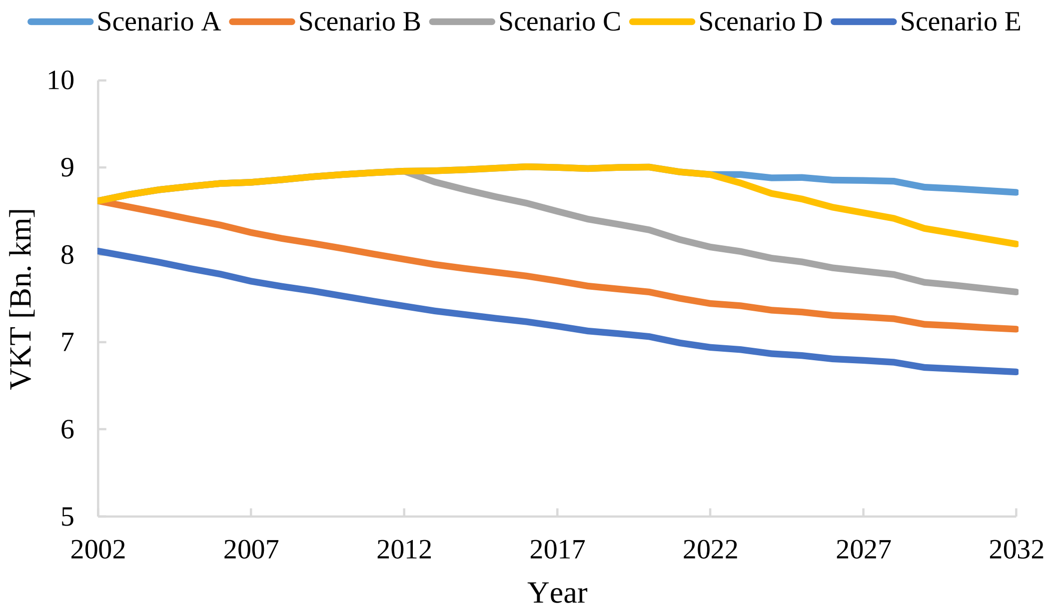


Figure 12 Total VKT Estimation of each Scenario

4.3 Results of Trip Length Estimation

This section presents two kind of the estimated results from MARS model, namely trip length as shown in Figure 13 to Figure 20. Additionally, the estimated results for trip length were simulated based on mode choices including non-motorized mode (i.e. pedestrian and bicycle), public transport (i.e. rail and bus), car and motorcycle.

Average trip length per mode, namely pedestrian, bicycle, and bus are likely to be the longest length when scenario B had introduced. Due to people shift their modes to rail transit as explained above, non-motorized mode such as walking and using bicycle is become to be the main mode for access to stations. On the other hand, the average trip length for rail was likely to be the longest when scenario A was implemented, while the average trip length for car and motorcycle tended to be the longest when scenario E was launched. These data were generated from variables of total trips and distances between each zone.

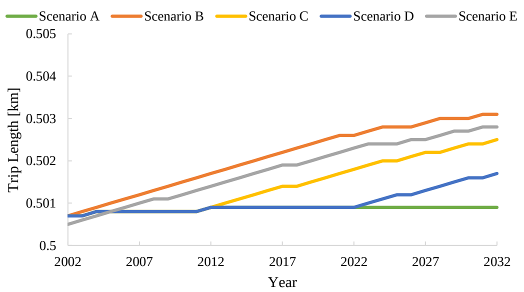


Figure 13 Trip Length of Pedestrian

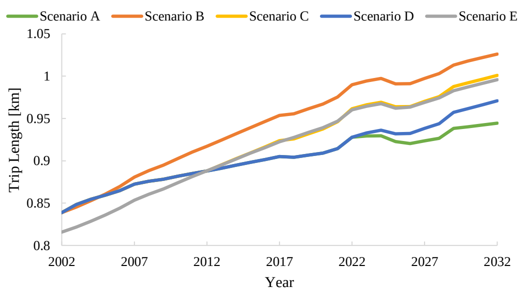


Figure 14 Trip Length of Bicycle

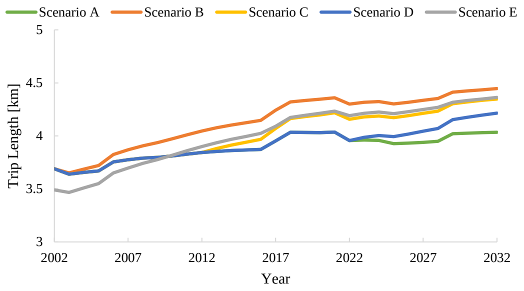


Figure 15 Trip Length of Bus

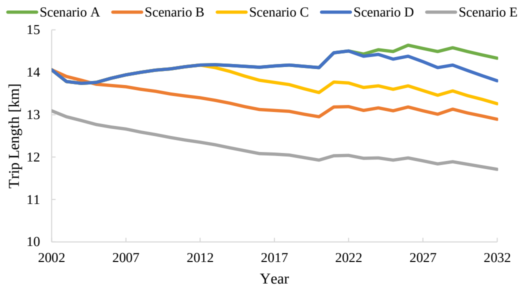


Figure 16 Trip Length of Rail

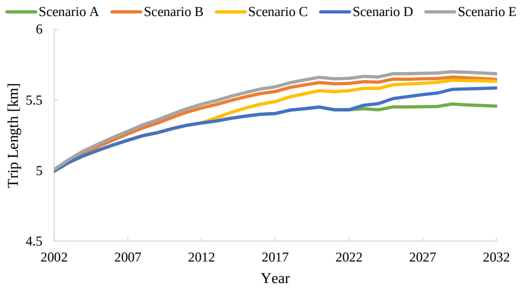


Figure 17 Trip Length of Car

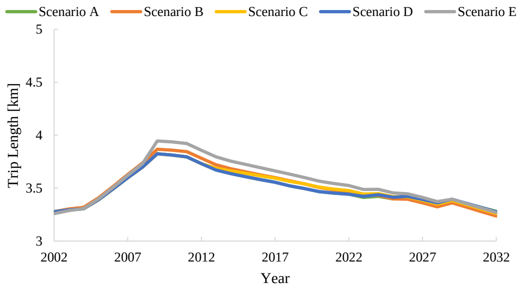


Figure 18 Trip Length of Motorcycle

4.4 Results of CO_2 Emission Estimation

This study aims to measure how much CO_2 emission can reduce after each policy scenario was introduced to Niigata city and its vicinities by using the MARS model. The equations used to estimate CO_2 emission was improved (Matsuhashi and others, 2004) and can be written as follow.

CO_2 emission estimation by car and motorcycle can be calculated as equation (1)

$$E_j = N_j \times V_j \times e_j \qquad (1)$$

where,

- j : Mode of transportation
- E_j : CO_2 emission
- N_j : Number of vehicles/motorcycles
- V_j : Vehicle Kilometer Travels
- e_j : CO_2 emission factor

The estimated CO_2 emission by rail and bus can be calculated as equation (2)

$$E_j = \sum \left(P_j \times e_j \right) \tag{2}$$

where,

P_j : Passenger km

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 static data from Ministry of the Environment, Japan, was used. The CO_2 emission factor is shown Table 1.

Table 1 CO_2 Emission Factor per Mode of Transportation

Mode	Car	Motorcycle	Bus	Rail
CO_2 Emission Factor [kg-CO_2per capita・km]	0.175	0.104	0.053	0.019

The results of CO_2 emission after implementing each policy scenario are shows in Figure 19. The estimated CO_2 emission of each scenarios in 2032 are scenario A: 1.54 [Mil. t-CO_2/year], Scenario B: 1.26 [Mil. t-CO_2/year], Scenario C: 1.34 [Mil. t-CO_2/year], Scenario D: 1.44 [Mil. t-CO_2/year], Scenario E: 1.18 [Mil. t-CO_2/year] as illustrated in Figure 19. As a result, minimum of CO_2 emission is Scenario E. Introduction of urban consolidation policy in early stage could reduce CO_2 emission. In addition, introduction of urban consolidation policy with improvement of head time for rail could reduce CO_2 emission more.

Finally, Figure 20 shows CO_2 emission per modes in 2032. As a result, CO_2 emission introduced urban consolidation policy only is constant because of average trip length per capita is shorter due to population consolidate to central of the city. Also, introduction of urban consolidation policy with improvement of head time for rail could reduce CO_2 emission because of the rail usage were increased.

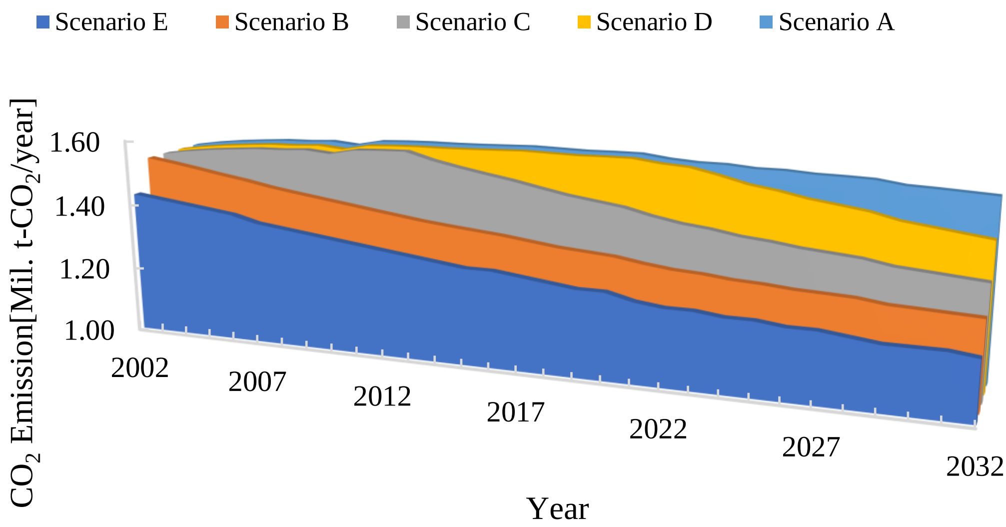


Figure 19 CO_2 Emission of each Scenario

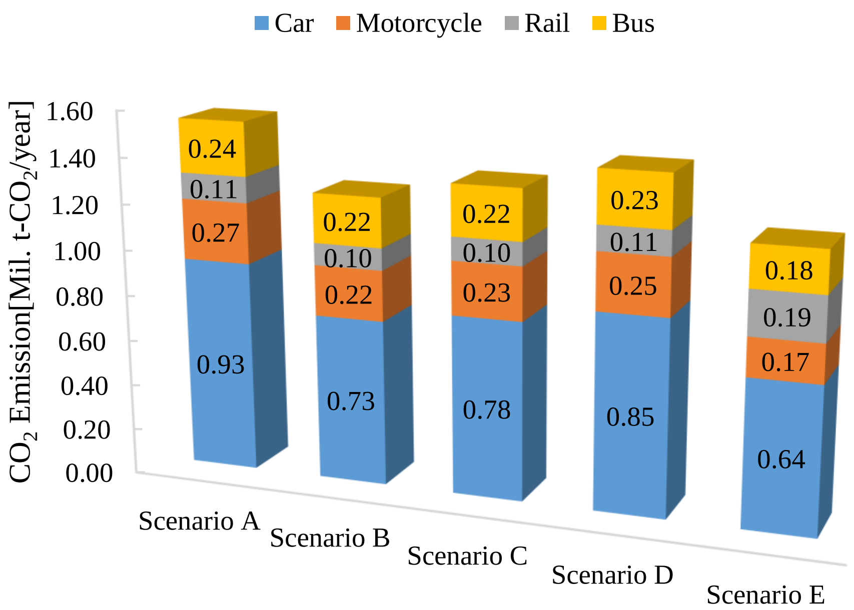


Figure 20 CO_2 Emission per Modes in 2032

5. Conclusion

This study was evaluated the introduction of urban consolidation policy from estimated CO_2 emission reduction. Concretely, 5 scenarios (Base case, Introduction of urban consolidation policy in 2002, 2012, and 2022, Improvement of rail transportation) were set. When the scenarios had set, CO_2 emission was estimated during 30 years from 2002 to 2032.

As a result, scenario of introduction of urban consolidation policy in the base year could reduce max. 17.9 % of CO_2 emission compared with Scenario A. In addition, scenario of introduction of urban consolidation policy with improvement of head time for rail could reduce max. 30.5 % of CO_2 emission compared with Scenario A, too. Also, in the city of high car utilization rate, population consolidated to central area in the city lead to reduce CO_2 emission because of the average trip length is shorter than before. But, to reduce of CO_2 emission by conversion to public transportation is desirable the introduction of urban consolidation policy with improvement of head time for public transportation.

Finally, as a results of CO_2 emission reductions, the introduction of urban consolidation policy in Niigata city could evaluate for high impacts to realize low carbon society.

In further studies, it is necessary to estimate CO_2 emission reductions when the transport network is changed and the impacts of introducing policies when commercial land, and work places are consolidated.

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