Integrated CO_2 Emissions Evaluation System for Climate Change Mitigation and Flood Risk Adaptation Scenarios

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Abstract

The realization of climate change mitigation and adaptation remains an urgent global issue. As a way of such mitigation and adaptation measures, moving people from flood-hazard areas to a compact city could be an effective measure. In this case, climate change mitigation and adaptation measures could be compatible. The objective of this study is to develop an integrated evaluation system for CO_2 emissions under several urban land-use scenarios (Yamagata and Seya, 2013; Yamagata et al., 2013) considering [i] land use (compact city and flood risk prevention) and [ii] the introduction of electric vehicles (EVs) and photovoltaic (PV) panels at a local town level on a city or a metropolitan area scale. The developed system can be used to assess the co-benefits of both mitigation and adaptation measures from the viewpoint of CO_2 emissions. Indirect emissions based on households' expenditure are also estimated in addition to direct emissions. In this study, the Tokyo Metropolitan Area was selected as a case study to apply this evaluation system.

1. Introduction

Scientific forecasts predict that climate change will raise the risk of climate disasters in the future. The climate change will be gradual, but extreme weather events will increase in intensity. Vulnerability created by the flooding is especially important for megacities in which many assets are located. So, we need to address climate change mitigation and adaptation at the same time. Under the present circumstances, there are not enough prospects for efficient GHG mitigation measures on the global scale. We must adapt to the impact of climate change in such a case where global mean temperatures could raise about 4 degrees Celsius in the present century compared with past preindustrial averages.

Current conventional urban policy has difficulty in coping with complex disasters (e.g. extreme weather events such as local heavy rainfall, sea level rise and tsunami caused by a typhoon and so on). After the Tohoku Earthquake, the concept of urban resilience has been discussed more widely in Japan. Resilient cities cannot be realized without considering energy and natural disaster risks. In case of sea-level change, the eco-system is also affected and managed retreat can be effective as one way of climate change adaptation (Gilman et al., 2008). The risk characteristics of the frequency and intensity of flooding disasters and the vulnerability of social systems including land-use change need to be analyzed. Although almost all local governments are pursuing measures for climate change mitigation, they have not focused on climate change adaptation as a priority policy yet. There is a need to review the interaction between climate change mitigation and adaptation measures, especially the co-benefits and trade-offs.

In the field of urban planning, climate change adaptation is already addressed in some projects such as Auckland Sustainability Framework, Megacity Research Project TP. Ho Chi Minh of Future Megacities Programme, and Suburban Neighbourhood Adaptation to Changing Climate (SNACC). In this study, we focus on the adaptation to flooding risk, especially considering land-use change. It is effective to reduce the damage by land-use regulation which distinguishes between the areas with disaster prevention measures and the areas with little infrastructure and buildings. For example, the land use is regulated depending on the degree of inundation height. Such regulation is introduced in Germany, Nicaragua, Ecuador and Czech. In Nagoya, Japan, buildings are controlled in the flood-hazard areas. However, the combination of other land-use regulations such as compact city is not considered. As flooding disaster prevention, it would be easiest and most effective if people could retreat from flood-hazard areas. In addition, if retreated people moved to the city center and located around train stations, GHG emissions could also be reduced. In this case, climate change mitigation and adaptation measures are compatible.

In fact, the automobile fuel consumption under land-use scenarios considering flood disaster prevention and compact city design in local cities has been quantitatively evaluated (Taniguchi et al., 2005). Nagao et al. (2012) considered the safety against disasters as one of the QOL index and selected retreat and cohesion areas in a local city. However, the Tokyo Metropolitan Area, which is still by far the largest Megacity in the world, is extremely vulnerable against climate risks, especially with flooding risk, because a large part of the assets is concentrating near the bay area. On the other hand, researchers are projecting the increase of flooding risks in the Tokyo Metropolitan Area, due to climate change as well as tsunami from future big earthquakes. We need to consider appropriate land-uses that are more resilient against climate risks in Megacities (Yamagata et al., 2013).

As for the CO_2 emission reduction potentials for the land-use scenarios, especially compact city, many studies have indicated that cities with low residential density rely on automobile transportation, and therefore the reduction of CO_2 emissions caused by transportation use would be attained by changing urban layout to a more compact one, which would lead to the increase of the use of public transportation and the reduction of trip length by car (e.g. Newman and Kenworthy, 1989; Hayashi et al., 1995; Jenks et al., 1996; Naess, 1996; Roo and Miller, 2000; Williams et al., 2000; Taniguchi et al., 2002; Nakamichi et al., 2007; Taniguchi et al., 2008).

Also, it is necessary to estimate indirect emissions as well as direct emissions to clarify the liability of daily energy consumption-based CO_2 emissions. Recently, many studies have started considering also the indirect emissions. (Abe et al., 2002; Nakamura and Otoma, 2004; Yamashita et al. 2007; Dhakal, 2009; Kennedy et al., 2009; Xi et al., 2011; Shigeto et al., 2012) Hence, in this paper, we also estimate the indirect emissions by allocating the emissions to the regions where the energy is consumed, using the data on the expenditure for households' daily life items.

In addition to the above mentioned mitigation measures with compact city scenarios, we also need to consider those with renewable energy use. Since the 2011 Tohoku Earthquake, the Japanese Government has gradually changed its energy policies toward distributed renewable energy generation. As a part of such efforts, the Japanese Diet has approved the "Act on the Purchase of Renewable Energy Sourced Electricity by Electric Utilities (Act)", which is a feed-in tariff regime for renewable energy, effective from 1 July 2012. Under the Act, electric utility operators are obligated to purchase electricity generated from renewable energy including solar photovoltaic (PV) power from suppliers for fixed feed-in tariff prices. The prices are higher than normal contractual prices and applicable for a fixed duration of 10 years in case of residential PV power.

This regime is widely expected to spur the introduction of PV panels and electric vehicles (EVs). If EVs were introduced in sets with PVs, they would be useful for zero-emission power generations and would serve as a power storage facility in the form of mobile batteries in the case of a blackout since they are disconnected by the loss of AC power (Yamagata and Seya, 2013).

In the Yamagata and Seya (2013) scenarios, it is expected that EVs and PV panels will be widely diffused in 2050. This paper considers the large-scale introduction of EVs and photovoltaic PV panels on the roofs of detached houses as a mitigation measure. Taniguchi and Ochiai (2011) evaluated the suitability of smart grids with an emphasis on the characteristics of each block and the behavior of residents and households at a residential block scale on the premise of existing technological level. Taniguchi and Ochiai (2012) analyzed the influence of future technological innovation on the suitability of smart grids at a block scale. Yokoi et al. (2010) estimated the CO_2 reduction potential of smart grids considering plans of block renewal at a regional scale. It is important to evaluate the CO_2 reduction potential combining both the large-scale introduction of smart grids and land-use change, namely considering not only climate change mitigation but also adaptation.

The objective of this study is to develop an integrated evaluation system for direct/indirect CO_2 emissions under several urban land-use scenarios (Yamagata and Seya, 2013; Yamagata et al., 2013) which consider [i] land-use change (a compact city and retreat from flood-hazard area) and [ii] introduction of EVs and PVs by using GIS, in order to assess the co-benefits or trade-offs of mitigation and adaptation. This study integrates a direct/indirect CO_2 emissions estimation model with spatially explicit land-use scenarios at a local town level. In this study, the Tokyo Metropolitan Area, which is still by far the largest Megacity in the world, is selected as a case study to apply the developed evaluation system.

2. Data and methodologies

2.1. Direct/indirect CO_2 emission estimation model

2.1.1. Definition of direct and indirect CO_2 emissions

CO_2 emissions fall into 2 types, direct emissions and indirect emissions. Easier to measure are the direct emissions that we are responsible for. This includes the amount of gas and kerosene we use in our houses and the amount of petrol or diesel we burn in our cars. Getting the carbon dioxide figures right for gas, petrol and diesel is quite straightforward, because a standard amount is released when each fuel is burnt. CO_2 in the electricity production process is emitted at power plants. Thus, it is defined as the direct emissions of the industrial sector. In contrast, the indirect emissions for households are defined as the CO_2 emissions allocated to the regions where the energy is consumed according to the expenditure of money on the items for households'daily life. In this study, the boundary of CO_2 emissions is extended to fuel production for household fuel use, agriculture for food production, and other production for consumption items including energy use for both production and transportation processes. The electricity, gas and kerosene used in houses are allocated as direct emissions of households. The petrol or diesel consumption is allocated to car registration place as direct emissions. It is useful to make a clear distinction among the CO_2 emissions caused by household consumption and to formulate an effective policy for the reduction of the total GHG emissions.

2.1.2. Data

With regard to the emission intensity (emission factor) data, we employed Embodied Energy and Emission Intensity Data (3EID). These data contain embodied environmental burden intensity data calculated using Japanese Input-Output tables. The Japanese Input-Output tables consist of approximately 400 commodity sectors. They represent the economic relationships among these sectors based on annual transactions. 3EID includes data on direct and indirect energy consumption or CO_2 emissions (i.e. environmental burden) from unit production activity (equivalent to one million yen). In this study, we employed the CO_2 emission intensity data estimated from consumer prices excluding imports. The emission intensity by prefecture and household type is calculated by Tanaka et al. (2008)'s method mentioned above.

Table 1. Emission groups of items

Emission group	Number of Items
1. Food	
Cereals	6
Fish & shellfish	5
Meat	6
Dairy products & eggs	3
Vegetables & seaweeds	9
Fruits	1
Oils, fats & Seasonings	2
Cakes & candies	1
Cooked food	13
Beverages	3
Alcoholic drinks	4
Eating out	12
Providing meals	1
2. Housing	2
3. Fuel, light & water charges	6
Electricity	
City gas	
LP gas	
Kerosene	
Water & sewerage charges	
Others	
4. Furniture & household utensils	31
5. Clothes & footwear	8
6. Medical care	8
7. Transportation & communication	
Public transportation	10
Private transportation (Gasoline)	13
Communication	6
8. Education	12
9. Reading & recreation	47
10. Others	27

For calculating the annual expenditure on each item, we employed the Household Expenditure Survey (HES). This is a survey conducted to investigate the actual state of household incomes and expenditures in terms of expenditure and consumption. We used the data collected in 2005 as the base year. This survey is performed every month for 981 consumption items for 8000 households in 168 villages, towns and cities all over Japan by Statistics Bureau, Ministry of Internal Affairs and Communications. The results of the survey are announced monthly and yearly for cities, regions, types of households (i.e. total number of households, households of more than two, single person households). In order to estimate CO_2 emissions from household consumption within a zone, we corresponded the items of HES to 3EID data of Fuel and lights, Transportation and communication, Food, and Others. For a detailed specification, see Tab. 1.

2.1.3. Estimation of direct/indirect CO_2 emissions

For the evaluation of land-use scenarios, we estimated the direct and indirect emissions at the neighborhood scale. Because urban improvement projects are implemented on such micro zone scales, the evaluation of the effect on the change of CO_2 emissions should be localized. In order to accurately estimate the lifecycle of CO_2 (LC-CO_2) related to household consumption, the emission intensity of each consumer goods (expenditure item), such as gasoline, food, etc. must be estimated. The categories of the items used in this study are shown in Tab. 1. Because emission intensity differs by region and by consumer (household) type, it is important to consider its heterogeneity. We employed the algorithm proposed by Tanaka et al. (2008), who had employed statistical methods (Bayesian estimation method and Genetic Algorithm) for estimating the emission intensity of each expenditure item by prefecture by seven household types (Tab. 2). The annual CO_2 emissions (kg-CO_2/year) in each zone (micro district at the neighborhood scale) i was calculated in the following manner:

$$CE_i = \sum_j H_{ij}[\sum_k E_{ijk}(ic_{ik} + dc_{ik})] \quad (1)$$

where,

CE_i: annual CO_2 emissions in each zone i (kg-CO_2/year)
H_{ij}: the number of household type j in zone i
E_{ijk}: annual expenditure on item k by household type j in zone i (yen/household/year)
ic_{ik}: emission intensity of indirect CO_2 for item k (kg-CO_2/yen)
dc_{ik}: emission intensity of direct CO_2 for item k (Gas, kerosene and gasoline) (kg-CO_2/yen)

Estimated CO_2 emissions of each household were allocated on the basis of the number of households in each of the 7 household types in each micro zone. The number of households was taken from the 2005 census. For example, Tab. 3 shows the estimated average CO_2 emissions per household of Yokohama City in 2005.

Table 2. Seven household types

Household type
a. One-person households (65 years of age or over)
b. One-person households (under 65 years of age)
c. Married couple only (either of them 65 years of age or over)
d. Married couple only (both under 65 years of age)
e. Married couple with child(ren)
f. Single parent and child(ren)
g. Other types

Table 3. Average CO_2 emission per household (e.g. Yokohama)

Emission group	Indirect CO_2 emissions ($kgCO_2$/year)	Direct CO_2 emissions ($kgCO_2$/year)
1. Food	1,530	0
2. Housing	154	0
3. Fuel, light & water charges	3,719	1,304
Electricity	(2,242)	(0)
City gas	(866)	(795)
LP Gas	(420)	(383)
Kerosene	(136)	(126)
Water & sewerage charges	(55)	(0)
Others	(0)	(0)
4. Furniture & household utensils	187	0
5. Clothes & footwear	349	0
6. Medical care	256	0
7. Transportation & communication	1,459	484
(Gasoline)	(559)	(484)
8. Education	136	0
9. Reading & recreation	655	0
10. Others	290	0
Total	8,735	1,788

2.2. Spatially explicit land-use model

So far, many integrated land-use and transportation models have been applied to real urban policy planning and the creation of land-use change scenarios. The present study employed a multi-market static economic equilibrium model based on urban economic theory (e.g., Ueda et al., 2013). In this study, we developed a spatially explicit land-use model which was created based on micro district level zones.

The structure of our model is given in Fig. 1. The major assumptions of this model are as follows: [1] There exists a spatial economy whose coverage is divided into zones *i*. [2] The total number of each household type *j*, say H_j in the metropolitan area is given (closed city). [3] The society is composed of three types of agents: households, developers, and absentee landlords. The behavior of each agent is formulated on the basis of microeconomic principles, that is, utility maximization by households and profit maximization by developers and absentee landlords. [4] Households belonging to the same type *j* have identical preferences. The households choose their locations in accordance with maximized utility. [5] There is one residential land market and residential (building) floor market in each zone. These markets reach equilibrium simultaneously. The model can output a set of variables which describe a real urban economy such as distribution of locators (households), distribution of land rent and building floor rent, land and building floor area, etc. The detailed mathematical description of our model and the input data is given in Yamagata and Seya (2013) and Yamagata et al. (2013). The ratio of detached houses is estimated using the projected population density using the relationship shown in Fig. 2.

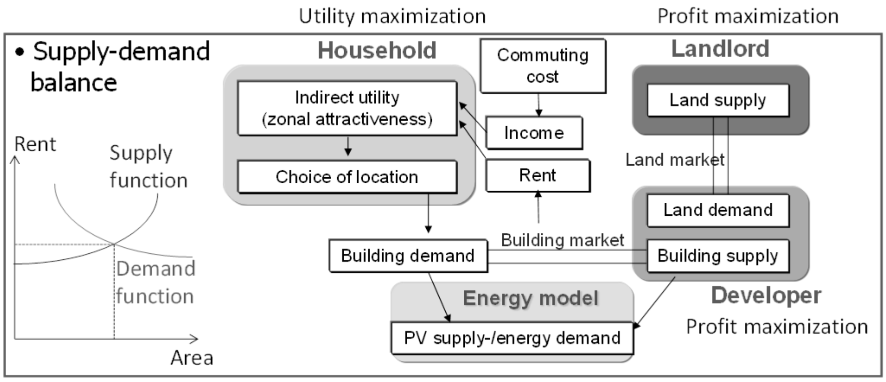

Fig. 1. Structure of our spatially explicit land-use model

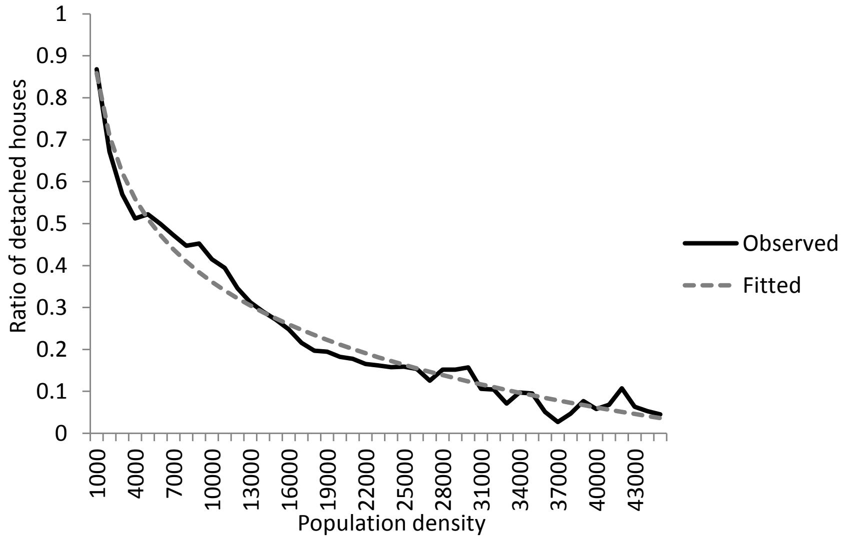

Fig. 2. Relationship between the ratio of detached houses and population density

2.3. Integrated CO_2 emission evaluation system

The structure of our integrated CO_2 emission evaluation system is seen in Fig. 3. We can use HES data not only for CO_2 emission estimation but also for energy demand estimation. Energy demand change can be projected even if EVs and PVs will be introduced. The installable area of roofs depends on the supply-demand balance of buildings which is provided by the land-use model.

As to EVs, the CO_2 emissions rate could be estimated as shown in Tab.4. In order to consider the change of percentage of the electricity supply source (from nuclear to thermal) after the Tohoku Earthquake, we calculated the CO_2 emission factor from April 2011 to March 2012 to be 0.50 ($kgCO_2/kWh$) using the reports of the federation of electric power companies of Japan.

As to PVs, we assumed that PVs were installed on the roofs of all detached houses in the study area. Following Yokoi et al. (2010), the hourly average of unit electric supply by PVs (kWh/h) can be estimated as

$$PV_i = I \times \tau \times L_i^{PV} \times \eta pc \times Kpt \times T \tag{2}$$

where I denotes the total (solar) irradiance ($kWh/m^2/h$);□τ: array conversion efficiency (=0.1); L^{PV}: installation area (m^2); □ηpc: running efficiency of power conditioner (=0.95); K_{pt}: temperature correction coefficient (=0.9221 for May to October, =1 for the other months); *T*: performance ratio (=0.89). I was taken from METPV-2 database. LPV is defined as

$$L_i^{PV} = L_i \times \xi \times \iota \times 1/\cos\psi \tag{3}$$

where ξ denotes the building-to-land ratio; ι : possible area of installation on the roof (=0.3); ψ : optimal angle of inclination (= 30 degrees). L_i was projected using our land-use model.

The introduction of EVs has the potential to reduce both direct and indirect emissions by gasoline use. Instead, indirect emission for electricity use would increase for the battery charge of EVs. As to the introduction of PVs, the indirect emission could be reduced because people would save electricity which was supplied by electric power company.

The outline of scenarios which could be assessed by our integrated CO_2 emissions evaluation system is described in Fig. 4. This evaluation system can be used as a decision support system for evaluation of CO_2 emissions under land-use scenarios considering climate mitigation and flood risk adaptation.

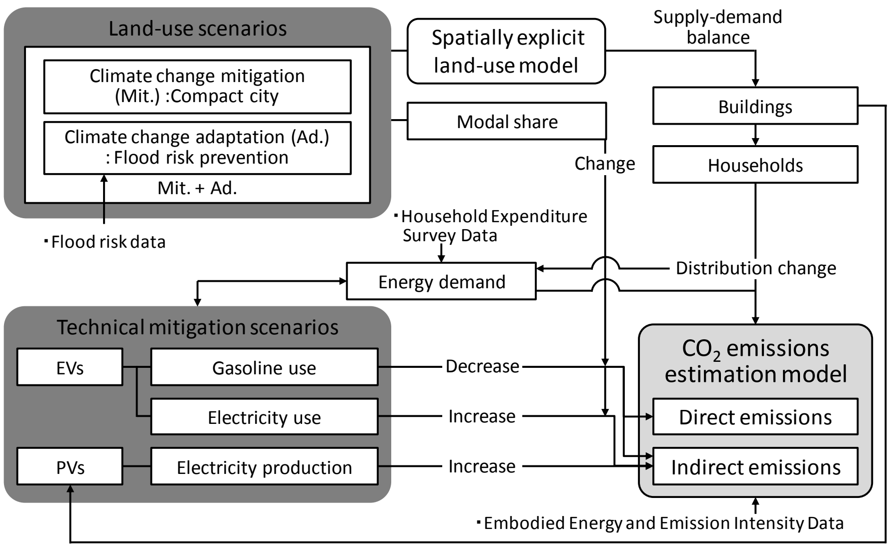

Fig. 3. Structure of integrated evaluation system for direct/indirect CO_2 emissions under land-use scenarios considering climate mitigation and flood risk adaptation

Table 4. CO_2 emission rate of EVs

Transportation Method	CO_2 Emissions (gCO_2/km)
Gasoline car	136.0 [1)]
EV (Lief)	62.1 [2)]
EV (i-MiEV)	55.1 [3)]

1) Calculated from Fuel consumption: 17.0km/L (MLIT, 2012)
2) Calculated from AC power consumption rate: 124Wh/km (Nissan, 2012)
3) Calculated from AC power consumption rate: 110Wh/km (Mitsubishi, 2012)

(JC08 mode)

All calculations are based on uniquely estimated CO_2 emission factors after the Tohoku Earthquake (2011): 0.50 $kgCO_2/kWh$

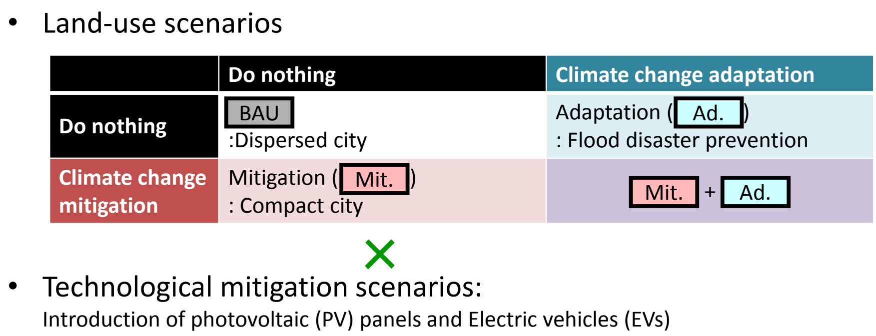

Fig. 4. Scenario outline

3. Case study

3.1. Scenario building for the Tokyo Metropolitan Area in 2050

The base year for projection is 2005, while 2050 is set as the target year by taking into account the reliability of projection results. The study area is shown in Fig. 5. We assumed that the number of households in each household type in 2050 would change and the ratios to the number in 2005 would be as follows: type 1: 2.07, 2: 1.07, 3: 1.39, 4: 0.66, 5: 0.69, 6: 1.32, 7: 0.85 This was estimated by the log-linear extrapolation of the estimates for 2030 by the National Institute of Population and Society Research, Japan.

Our future urban scenario is described in Tab. 5. We set four land-use scenarios and five introduction scenarios of PVs and EVs. We combined each scenario.

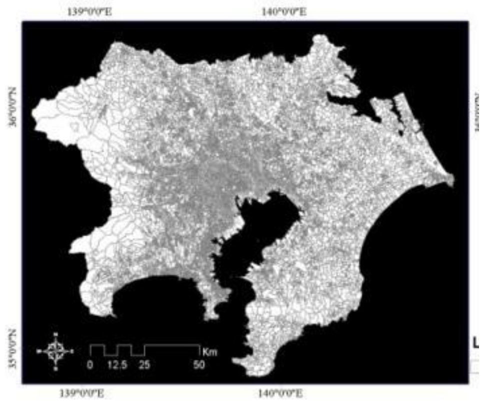

Fig. 5. Study area (Tokyo Metropolitan Area)

3.1.1. Land-use scenarios

We created four land-use scenarios, climate change mitigation (compact city), adaptation (flood risk prevention), mitigation + adaptation and a dispersion city (BAU), to show the possible range of future land-use changes based on Yamagata and Seya (2013) and Yamagata et al. (2013).

- Business-as-usual (BAU)

  We assume that the suburban development will continue to compare with other scenarios.
- Climate change mitigation scenario (Mit.)

  Regulations of land use will be introduced based on the concept of compact city. The compact city is known as one of the climate change mitigation measures. People will retreat from the suburbs and live in the city center and around train stations.
- Climate change adaptation scenario (Ad.)

  As a way of flood disaster prevention, we assume that people retreat from flood-hazard areas. The liquefaction risk index is used as a proxy index of flood and tsunami risk because both indexes are high near the bay area and river. The liquefaction risk index is calculated based on the methodology of Wakamatsu et al. (2005). The index runs from 0 (no risk) to 3 (high risk) as seen in Fig. 6. We defined 2 (middle risk) and 3 (high risk) as the flood-hazard areas.
- Climate change mitigation and adaptation scenario (Mit. + Ad.)

Table 5. Scenarios for the Tokyo Metropolitan Area in 2050

Technological Mitigation / Land-use	**Without technological mitigation measures**	**With technological mitigation measures (introduction of PVs and EVs)**
Climate change mitigation (Mit.) :Compact city	・ **Shrinking urbanized areas in suburb.** Available area of the residential land will be ½ (if distance to station is > 500m) ・ **Subsidy to living in the central district.** One hundred thousand yen/year (if distance to station is < 250m) ・ **Modal share will be changed.** Car trips around the train stations will be reduced by 50% (if distance to station is < 250m)	**In addition to the left column,** ・ **Cars will be replaced by EVs** Gasoline consumption will be zero but the electricity consumption for charging EVs will increase ・ **PV panels will be installed on the roofs of all the detached houses** Generated electricity from PVs will be subtracted from the electricity consumption of households ・ **Cars will be replaced by EVs.** ・ **PV panels will be installed on the roofs of the detached houses.**
Climate change adaptation (Ad.) : Flood risk prevention	・ **Retreat from the flood-hazard areas.** Available area of the residential land will be ½ (if the liquefaction risk index is 2 (middle) or 3 (high))	
Climate change mitigation and adaptation (Mit. + Ad.)	・ **Retreat from the flood-hazard areas.** ・ **Shrinking urbanized areas in suburb.** ・ **Subsidy to living in the central district.** ・ **Modal share will be changed.**	
Dispersion (BAU)	・ **Business as usual** The suburban development will continue	

We set a combination scenario that satisfies the conditions of both climate change mitigation and adaptation scenario. People will retreat from suburban and flood-hazard areas and will live in city center and around train stations.

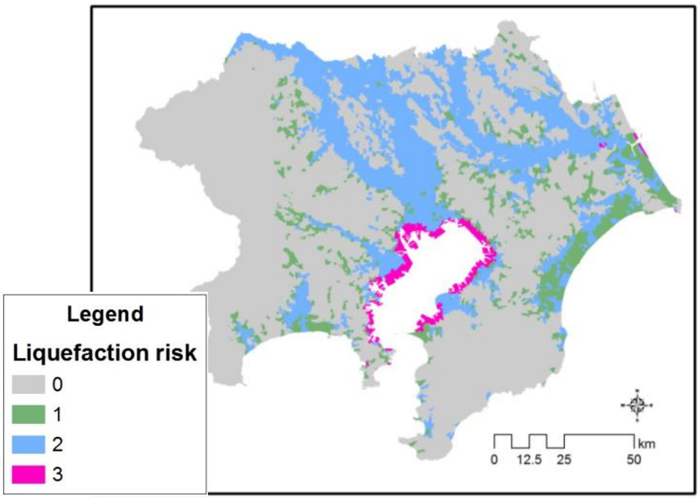

Fig. 6. Calculation results of the liquefaction risk index

3.1.2 Introduction scenarios of PVs and EVs

As mitigation measures, we considered not only land-use change like a compact city but also the large-scale introduction of EVs and PVs. In each land-use scenario, we set a different rate of diffusion for EVs and PVs (Tab. 6).

Table 6. Introduction scenarios of PVs and EVs

Introduction scenarios of PVs and EVs	Diffusion rate of EVs (%)	Diffusion rate of PVs(%)
1	0	0
2-i	100	100
2-ii	50	50
2-iii	100	50
2-iv	100	30

3.2. Results and discussion

The spatial distributions of population under each land-use scenario are shown in Fig. 7. Fig. 8 shows the distribution of CO_2 emissions in the Tokyo Metropolitan Area under different scenarios. The total CO_2 emissions from households could be reduced as seen in Fig. 9.

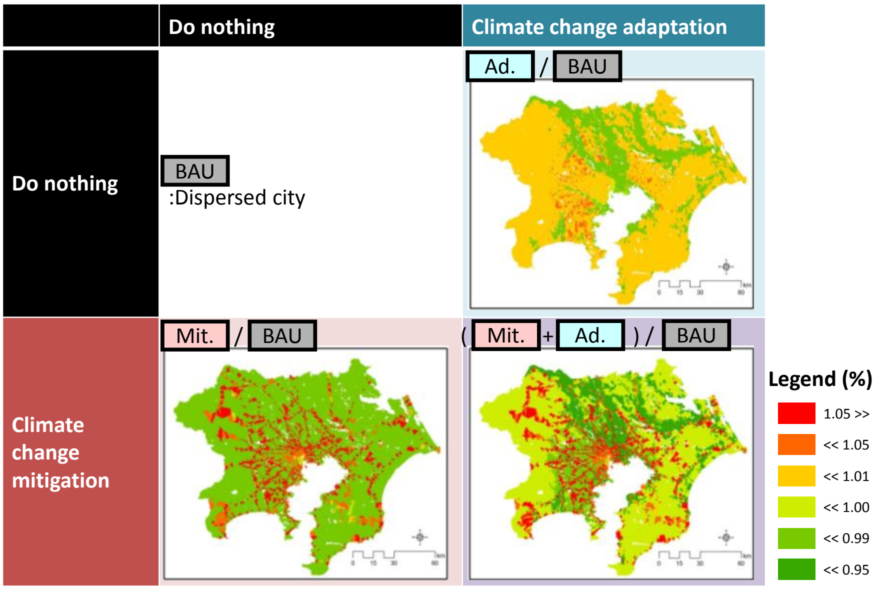

Fig. 7. The change rate of population distribution

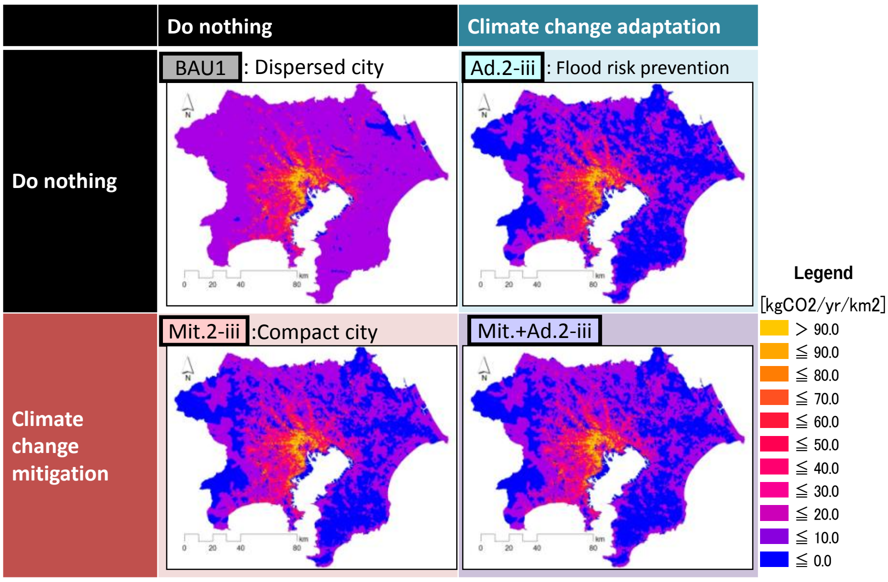

Fig. 8. Spatial distribution of direct and indirect CO_2 emissions of households under each scenario in the Tokyo Metropolitan Area

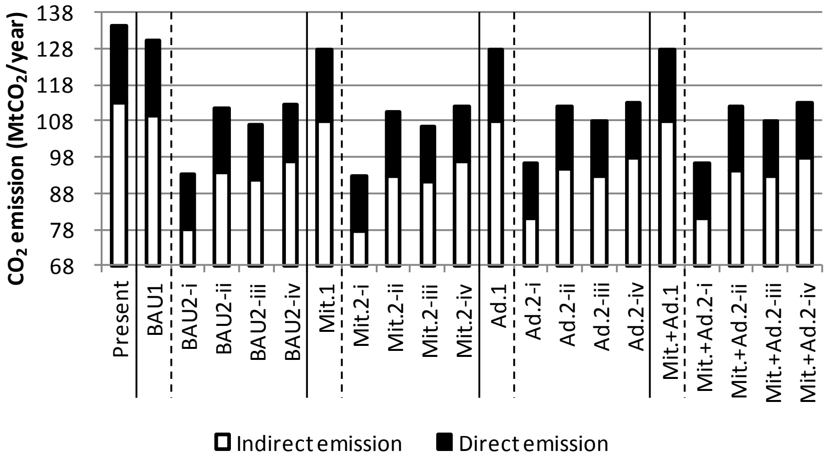

Fig. 9. CO_2 emissions of all the households under different scenarios

Even without technological mitigation measures (introduction of PVs and EVs), the estimated CO_2 emissions are likely to decrease by 3.2% depending on the population decline in the Tokyo Metropolitan Area in 2050. The reduction rate of scenario Mit.+Ad.1 (5.0%) is higher than that of scenario Ad.1 (4.8%) implying that CO_2 emissions can be reduced if compact city is realized. The reduction rate of transportation energy which Taniguchi et al. (2005) estimated for local city is about 3% under compact city scenario and 6% under the scenario considering both compact city and flood disaster prevention. The depopulation of the whole city is not considered in this study. Nakai and Morimoto (2008) calculated the change of both automobile energy consumption in the transportation sector and electric power consumption in the residential sector in some cases of implementing a compact city policy for the central city of a local area. The reduction rates are 2.5-4.2% in the transportation sector and 1.5-4.0% in the residential sector. The target year is 2020 and the depopulation of whole city is included in these scenarios. Such energy consumption has a direct correlation with CO_2 emissions. Because these cities are automobile dependent cities, the reduction rate in the transportation sector generally becomes higher than in the cities in the metropolitan area. Nakamichi et al. (2013) assumed a more compact city scenario in Yokohama city included in Tokyo Metropolitan Area, and estimated the CO_2 emissions from all sectors (direct and indirect emissions). The reduction rate was 5.4% under the compact city scenario. The assumptions, the target year and target area are not the same among these scenarios. However, they show the reduction rates are only several percentages or more. Compared with these studies, the estimated reduction rate of this study is not so low.

Under the scenarios with technological mitigation measures (BAU2, Mit.2, Ad.2, Mit.+Ad.2), the introduction of EVs has the potential to reduce both direct and indirect emissions by gasoline use (Emission group: 7. Transportation & communication). Instead, indirect emissions in Emission group 3 (Fuel, light & water charges) will increase due to the battery charge of EVs. As to the introduction of PVs, some or all of the electric power demand of each household could be covered by PV power generation. The indirect emissions in Emission group 3 could be reduced because people would save electricity supplied by the electric power company.

With technological mitigation measures, the CO_2 reduction rate of scenario Mit.2 (16.9%-31.0%) is higher than that of scenario BAU2 (16.5%-30.7%) while, on the other hand, the CO_2 reduction rate of scenario Ad.2 (16.1%-28.4%) is lower than that of scenario BAU2 (reduction rate of CO_2 emissions: Mit.2-i>BAU2-i>Ad.2-i, Mit.2-ii>BAU2-ii>Ad.2-ii, Mit.2-iii>BAU2-iii>Ad.2-iii, Mit.2-iv>BAU2-iv>Ad.2-iv). Even under the Mit.+Ad.2 scenarios, the CO_2 emissions are much more than in the BAU2 scenarios. The reduction rate of CO_2 (16.1%-28.5%) is lower by 2.0% compared with scenario Mit.2 only. This is due to the fact that PV panels could not be installed on the roofs of fewer detached houses depending on the decrease in the number of people living in flood-hazardous areas. It is important to formulate compatible ways between climate mitigation and adaptation. However, we can achieve more CO_2 reduction through parallel efforts on climate mitigation and adaptation measures because the reduction rate by technological mitigation measures is very high. Simultaneous discussions on both mitigation and adaptation are necessary.

4. Conclusions and recommendations

This study developed an integrated evaluation system for CO_2 emissions under [i] land-use scenarios considering both climate change mitigation and adaptation and [ii] technological mitigation scenarios considering the introduction of PVs and EVs. The land-use scenarios built by using a spatially explicit land-use model, which had been based on real estate, were applied for the case study of this evaluation system. Our CO_2 emission estimation model could estimate not only direct emissions but also indirect emissions based on household expenditure. As a case study, we showed the future spatial distribution of CO_2 emissions by using this integrated evaluation system.

This evaluation system could be used as a decision support system for the evaluation of CO_2 emissions under land-use scenarios considering climate mitigation and flood risk adaptation for resilient cities. Urban and regional planners might implement economically-based planning of urban improvement projects, spatial distribution of population density, public transportation projects and energy saving of households. They could also select retreat and cohesion areas considering compact city design and disaster prevention on a neighborhood scale. A different diffusion rate of PVs and EVs in each zone could be set as scenarios. Policy-makers could compare each effect on CO_2 emissions reduction.

The results of this case study suggest that climate change mitigation and adaptation can generate both a synergistic and trade-off effect from the viewpoint of CO_2 emissions. We have to find a strategy for compatibility between mitigation and adaptation using an evaluation system like this study.

The results suggest that the compactness of land-use and the introduction of PV panels installed on detached houses are not compatible from the viewpoint of CO_2 emission reduction because more compactness means fewer detached houses. In the future, we should consider scenarios assuming the installation of PV panels in apartment/office buildings in the city center or around stations and the introduction of mega solar power plants in suburban areas where people retreated. We postpone these considerations to future research. It is necessary to consider the interchange of surplus electricity generated by PVs needs. The electric power interchange among the household types with different living hours should also be considered, as pointed out by Taniguchi and Ochiai (2012). In this study, the indirect emission was estimated per year. The variations in time for both PV supply and household demand must be considered as pointed out by Esteban et al. (2012). The emissions were related to energy and gasoline change by scenarios. Emissions from other sources should be considered from the viewpoint of Life Cycle Assessment. Also, the cost for realizing land-use scenarios such as people's move should be calculated and compared with the cost of infrastructure for flood disaster prevention such as levee and padding based on cost-benefit analysis. The dispersed city has the potential of making services inefficient in the city and of increasing the cost for infrastructure. Because the compact city may be economical and efficient in consideration of CO_2 emissions by logistics, further studies are needed from this viewpoint, too. Furthermore, the scenarios should be evaluated in terms of QOL such as accessibility and amenity. In order to realize a climate change adaptation scenario, risk communication tools like Burch et al. (2010) and resilience against multiple disasters including earthquake and tsunami are also important.

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