CO_2 Emissions Evaluation Considering Introduction of EVs and PVs under Land-use Scenarios for Climate Change Mitigation and Adaptation - Focusing on the Change of Emission Factor after the Tohoku Earthquake-

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Abstract: After the Tohoku Earthquake, the concept of urban resilience has been discussed widely in Japan. Resilient cities cannot be realized without considering energy and natural disaster risks. In this paper several land-use scenarios are used for the Tokyo Metropolitan Area in 2050 using a land-use model considering these two aspects. These scenarios consider the co-benefits of [i] change of urban form (compact city), [ii] adaptation to flooding risks, and [iii] diffusion of electric vehicles (EVs) and solar photovoltaic (PV) panels. Also, in this paper the effects of emission factor change on direct/indirect CO_2 emissions due to the shutdown of nuclear power plants after the earthquake are analyzed. The results suggest that the diffusion of PVs is more important in the non-nuclear world to reduce CO_2 emissions, and that EVs still can contribute to CO_2 emission reduction despite changes in emission factor. Also, compact urban form can effectively reduce CO_2 emissions.

Keywords: Emission Factor, Climate Change Mitigation and Adaptation, Direct and Indirect CO_2 Emissions, EVs, PVs, Land-use Scenario

1. INTRODUCTION

Since the 2011 Tohoku Earthquake, the Japanese Government has gradually changed its energy policies toward distributed power 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 a fixed feed-in tariff price. The price is higher than normal contractual prices and is 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 generation 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. 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 on 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 on a block scale. Yokoi et al. (2010)

estimated the CO_2 reduction potential of smart grids considering plans of block renewal on a regional scale. Since 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 mitigation measures.

Japan has shut down more than 95% of its nuclear power plants since the Tohoku earthquake, due to the accident of the Fukushima Daiichi nuclear power plant. In order to replace the electric power generated by the nuclear power plants, some thermal power generators have been restarted in Japan, which inevitably worsen the emission factor. Hence it is important to quantify the effects of worsened emission factor, and also to offset those effects by the introduction of low-carbon technologies such as PVs and EVs. The impact of this increasing emission factor should be compared with the effect of the introduction of PVs and EVs on CO_2 emission reduction.

Many climate modelers predict that climate change will be magnified, raising the risk of natural disasters in the future. They further say that climate change will be gradual, but extreme weather events will increase in frequency and intensity. Vulnerability created by water-related disasters is especially substantial for Megacities in which many assets are concentrated. At the same time, we should also address climate change mitigation and adaptation. Under the present circumstances, unfortunately, there are not enough prospects for efficient mitigation measures of GHG emissions on a global mass scale. We must adapt to the impact of climate change in case that global mean temperatures will raise about 4 degrees Celsius in the present century compared with past preindustrial averages. Current conventional ways of urban policy have extreme 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 options (Gilman et al., 2008). The risk characteristics of the frequency and intensity of water related disasters and the vulnerability of social systems including land-use change need to be projected. Although almost all local governments are pursuing measures for climate change mitigation, they have not focused on climate change adaptation as a policy yet. There is an urgent need to review the interaction such as the co-benefits and trade-offs between climate change mitigation and adaptation measures.

In the field of urban planning, climate change adaptation is addressed in some projects such as the 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 water-related disaster risk, especially considering land-use change. It is effective for reducing the damage by land-use regulations which distinguish between areas with enhanced disaster prevention measures and areas with limited urbanization as well as physical development of infrastructure and buildings. For example, 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 flood hazard areas. However, the combination with land-use regulations like in a compact city is not considered. As a way of flood disaster prevention, it would be effective that people could retreat from flood-hazard areas. Along with this, if retreated people would live in the city center and around train stations based on the concept of compact city, GHG emissions could be reduced as one of the mitigation measures. It means that climate change mitigation and adaptation are compatible.

Automobile fuel consumption under land-use scenarios considering flood disaster prevention and compact city design in a local city was quantitatively evaluated by Taniguchi et al. (2005). Nagao et al. (2012) considered safety for disaster as one of the QOL indexes and selected retreat and cohesion areas in a local city. The Tokyo Metropolitan Area, which is still by far the largest Megacity in the world, is extremely vulnerable against climate risks, especially flood risk, because a large part of assets is concentrated near the bay area. Climate research projects 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.

As for the evaluation of land-use change scenarios, especially compact city, many studies have indicated that cities with low residential density rely disproportionately 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, 1999; Hayashi et al., 1995; Jenks et al., 1996; Naess, 1996; Roo and Miller, 2000; Williams et al., 2000; Nakamichi et al., 2007; Taniguchi et al., 2008). Also, it is very important to estimate indirect emissions as well as direct emissions to clarify the responsibilities of daily energy consumption activities. Recently, many existing studies have started to cover CO_2 emissions considering indirect emissions. (Abe et al., 2002; Nakamura and Otoma, 2004; Yamashita et al. 2007; Dhakal, 2009; Kennedy et al., 2010; Xi et al., 2011; Shigeto et al., 2012) Hence, in this paper, not only the direct but also the indirect emissions are projected by allocating the emissions to the regions where the energy is consumed, using the data on the expenditure for households' daily life items. It is important to comprehend the direct and indirect CO_2 emission reduction potential of both the large-scale introduction of smart grids and land-use change considering not only climate change mitigation but also adaptation.

The objective of this study was to evaluate direct/indirect CO_2 emissions under the EVs and PVs introduction scenarios and land-use scenarios considering climate change mitigation and flood risk prevention by using GIS, in order to assess the impact of increasing emission factor. For creating the scenarios, this study used a spatially explicit land-use model (Yamagata et al., 2013) at a local town level. As a mitigation measure, we considered not only land-use change like a compact city but also the large-scale introduction of EVs and PV panels on the roofs of houses. Indirect emissions based on households' expenditure were also estimated in addition to emissions related to direct energy consumption. In this study, the Tokyo Metropolitan Area, Japan, which is still by far the largest Megacity in the world, was selected as a case study to evaluate the impact of increasing emission factor on each scenario.

2. DATA AND METHODOLOGY

2.1 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 collection

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 was calculated by Tanaka et al. (2008)'s method mentioned above.

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 matched the items of HES to 3EID data of Fuel and lights, Transportation and communication, Food, and Others. For a detailed specification, see Table 1.

2.1.3 Estimation of direct and indirect CO_2 emissions

For the evaluation of land-use scenarios, we estimated the direct and indirect emissions on the neighborhood scale. Because urban improvement projects are implemented on such micro zone scale, the evaluation of the urban improvement projects on the change of CO_2 emissions should be localized. In order to accurately estimate the lifecycle-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 Table 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 (Table 2). The annual CO_2 emissions (kg-CO_2/year) in each zone (micro district on 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. Table 3 shows the estimated average CO_2 emissions per household of Yokohama City in 2005.

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

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 emissions 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 (e.g., Ueda et al., 2013). The present study employed a multi-market static economic equilibrium model based on urban economic theory (e.g., Tsutsumi et al., 2013). Since our model is constructed at very spatially fine zones, we only used the residential land use part of the model (i.e., we did not consider the firm behavior and transportation model). The structure of our model is given in Fig. 1. The detailed mathematical description of our model and the input data is given in Yamagata and Seya (2013).

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). Households belonging to the same type j have identical preferences. [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] The households choose their locations in accordance with maximized utility. [5] There is one residential land market and one 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 number of zones in our study was 22603.

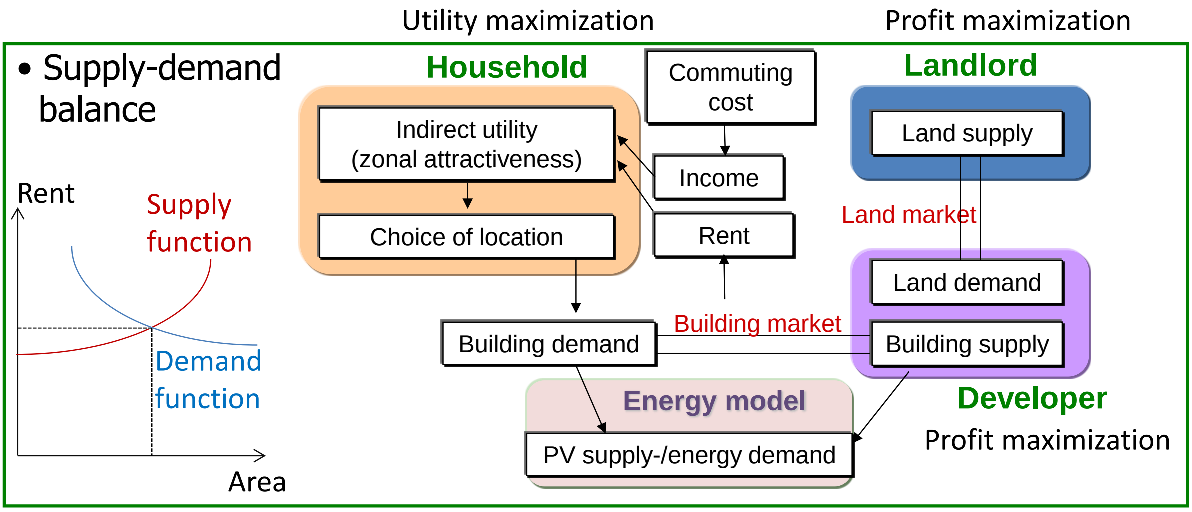


Figure 1. Structure of our spatially explicit land-use model

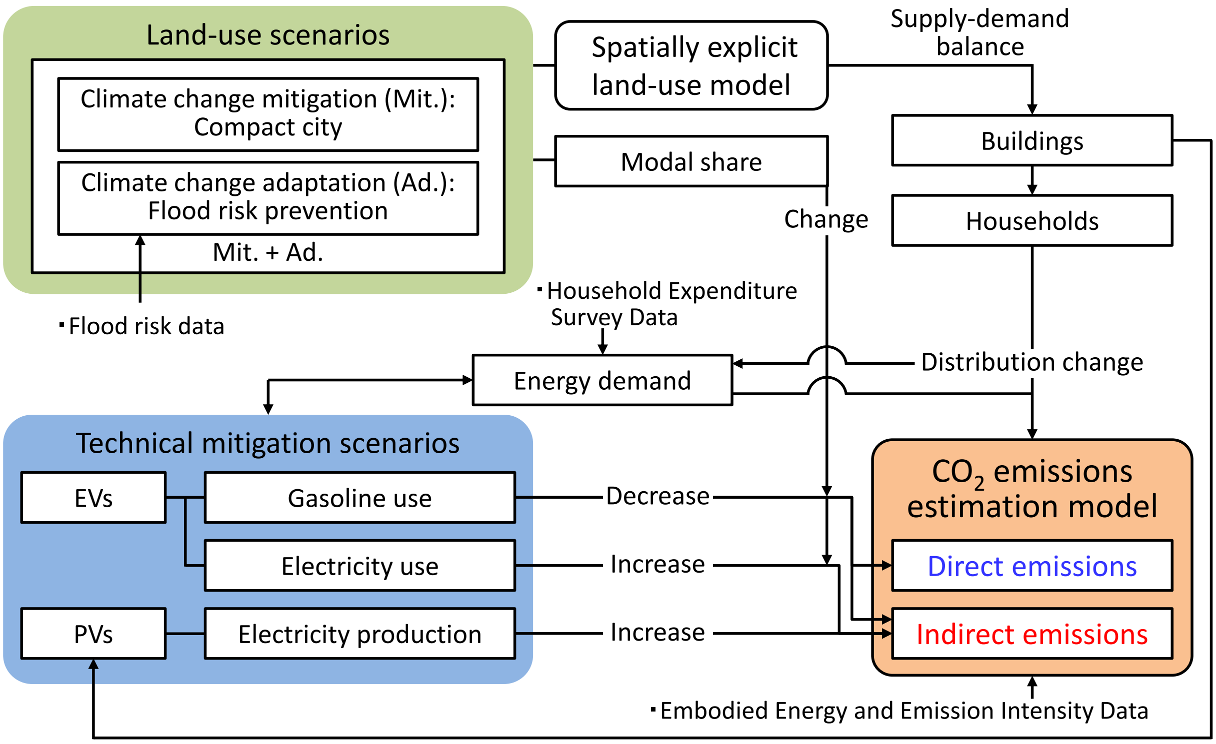


Figure 2. Structure of integrated evaluation model for direct/indirect CO_2 emissions under land-use scenarios considering climate mitigation and flood risk adaptation

2.3 Integrated CO_2 Emissions Evaluation Model

The structure of our integrated CO_2 emissions evaluation model is seen in Fig. 2. 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 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); LPV: installation area (m^2); ηpc: running efficiency of power conditioner (=0.95); *Kpt*: 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. The possible installation area L^{PV} 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 is the estimate of land area by the land-use model. We confirmed using "City Planning Basic Survey" data that $L_i \times \xi$ is a good approximation of the actual building area in Yokohama city (R-squared is approximately 0.69).

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

3. PROJECTION AND SCENARIOS

3.1 Projection of CO_2 Emission Factors

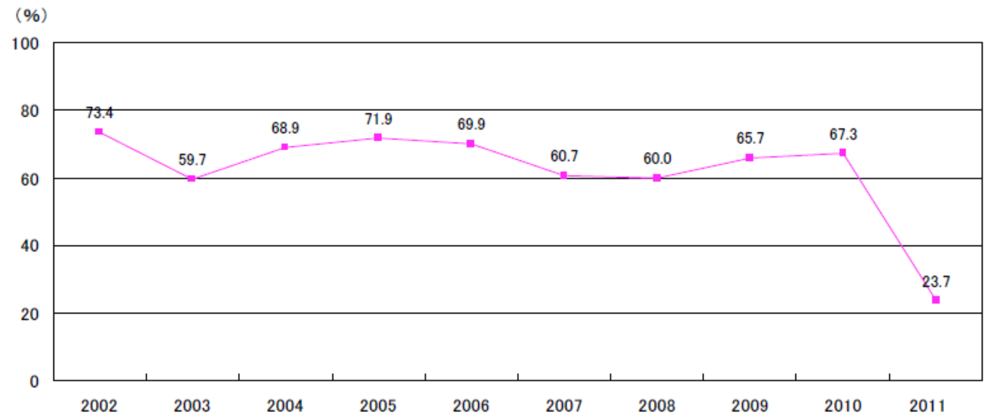
Firstly, we forecast the change of CO_2 emission factors. Although emission factors until 2011 have already been published, they are not yet released for 2012. We uniquely calculated the emission factor in 2012 based on The Federation of Electric Power Companies of Japan (2012a and 2012d) as seen in Table 4. Since the emission factor of electricity received from other companies (not the ten regional electric power companies) is not released, we assumed that it was equal to the one in 2011.

In order to estimate any future emission factor, we should grasp the change of utilization rate of nuclear power plants (Fig. 3). We estimated the future emission factor to be used for scenario building as 0.60 kgCO_2/kWh (Fig. 4). We applied the estimated emission factors in 2011 and 2050 in the scenarios.

Table 4. Estimated CO_2 emission factors for 2012

	1990[1)]	2008[1)]	2009[1)]	2010[1)]	2011[1)]	2012[2)]
Amount of electricity used (hundred million kWh)	6,590	8,890	8,590	9,060	8,600	8,607
CO_2 emissions (hundred million tonCO_2)	2.75	3.95	3.01	3.17	4.09	4.87
End-user based CO_2 emission factor (kgCO_2/kWh)	0.417	0.444	0.412	0.413	0.510	0.566

1) Source: The Federation of Electric Power Companies of Japan (2012b). Years mean fiscal year (from April to March)
2) Uniquely estimated in this study, from January to December



Source: The Federation of Electric Power Companies of Japan (2012c)

Figure 3. Change of nuclear power plant utilization rate

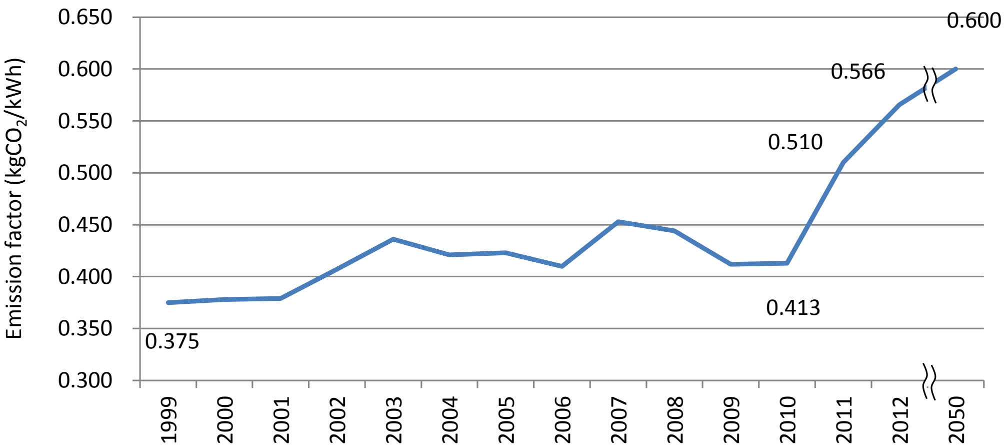


Figure 4. Estimated CO_2 emission factors for future scenarios

3.2 Scenario Building for the Tokyo Metropolitan Area in 2050

The base year for projection is 2005, while 2050 was 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, as a result, 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.

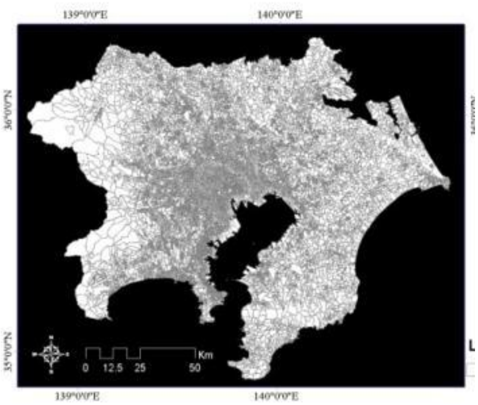


Figure 5. Study area (Tokyo Metropolitan Area)

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

We created four land-use scenarios: climate change mitigation (compact city) scenario, adaptation (flood risk prevention) scenario, mitigation + adaptation scenario and a dispersion city (BAU) scenario, to show the possible range of future land-use changes.

Table 5. Scenarios for the Tokyo Metropolitan Area in 2050

Technological mitigation / Land use	**Without technological mitigation measures**	**With technological mitigation measures (the 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 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 all detached houses**
Climate change adaptation (Ad.): Flood risk prevention	・ **Retreat from 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 flood-hazard areas** ・ **Shrinking urbanized areas in suburb** ・ **Subsidy to living in the central district** ・ **Modal share will be changed**	
Dispersed city (BAU)	・ **Business as usual** The suburban development will continue.	

3.2.1 Land-use scenarios

1) Business as usual (BAU)
To compare with other scenarios, we assumed that suburban development would continue.
2) Climate change mitigation scenario (Mit.)
Regulations of land-use would be introduced based on the concept of compact city. The compact city is known as one of climate change mitigation measures. People would retreat from the suburbs and live in the city centers and around train stations.
3) Climate change adaptation scenario (Ad.)
As a way of flood disaster prevention, we assumed that people would retreat from flood-hazard areas. The liquefaction risk index was 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 was 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 (moderate risk) and 3 (high risk) as the flood-hazard areas.
4) Climate change mitigation and adaptation scenario (Mit. + Ad.)
We set a combination scenario that satisfies the conditions of both climate change

mitigation and adaptation scenario. People would retreat from suburban and flood-hazard areas and would live in the city center and around train stations.

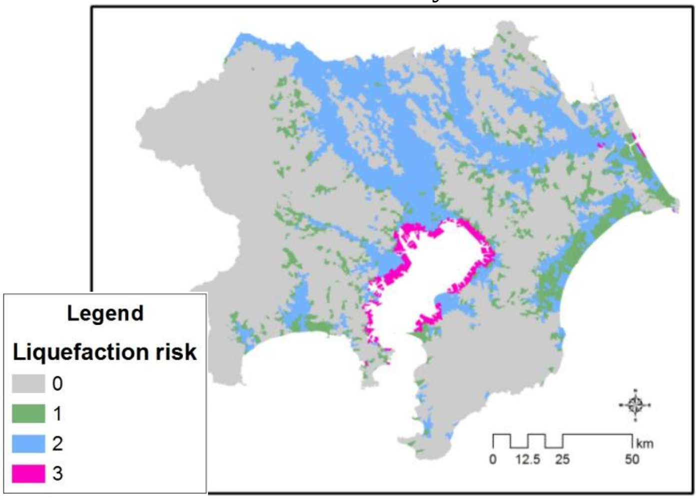


Figure 6. Calculation results of the liquefaction risk index

3.2.2 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. The diffusion rate of residential PV systems was 3.6% on national average (Chugoku Bureau of Economy, Trade and Industry, 2012). In each land-use scenario, we set a different diffusion rate for EVs and PVs (Table 6). Although some cases are extreme, we conducted sensitivity analyses. As to EVs, the CO_2 emission rate could be estimated as shown in Table7.

Table 6. Introduction scenarios of PVs and EVs

Introduction scenarios of PVs and EVs	Diffusion rate of EVs (%)	Diffusion rate of PVs (%)
0	0	0
100	100	100
50	100	50
30	100	30
20	100	20

Table 7. CO_2 emission rate of EVs

Transportation method	CO_2 emissions (gCO_2/km)			
	Based on CO_2 emission factor in 2010 [a)]	Based on CO_2 emission factor in 2011 [a)]	Based on estimated CO_2 emission factor for 2012 [b)]	Based on estimated CO_2 emission factor for 2050 [b)]
Gasoline car [1)]	136.1	136.1	136.1	136.1
EV (LIEF) [2)]	51.2	63.3	70.1	74.4
EV (i-MiEV) [3)]	45.4	56.2	62.2	66.0
HV (PRIUS) [4)]	73.5	73.5	73.5	73.5
PHV: (PRIUS PHV) [5)]	47.2	58.4	64.7	68.6

1) Fuel consumption: 17.0 km/L (MLIT, 2012)
2) AC power consumption rate: 124 Wh/km (Nissan, 2012),
3) AC power consumption rate: 110 Wh/km (Mitsubishi, 2012)
4) Fuel consumption rate: 30.4-32.6 km/L (Toyota, 2012)
5) AC power consumption rate in EV mode: 8.74 km/kWh (Toyota, 2012)
(JC08 mode)
a) Source: The Federation of Electric Power Companies of Japan (2012b), b) Uniquely estimated in this study

4. RESULTS AND DISCUSSION

The spatial distributions of population under each land-use scenario are shown in Figures 7, 8 and 9. Figures 10-17 show the spatial distribution of CO_2 emissions in the Tokyo Metropolitan Area under different scenarios. The total CO_2 emissions from all households could change as seen in Figures 18 and 19. Each scenario is described as a shortened form using the name of land-use scenarios and the numbers in Table 6. (e.g. BAU-0: Business as usual without the introduction of PVs and EVs, Mit.+Ad.-20: Climate change mitigation and adaptation scenario with a diffusion rate of 100% of EVs and 20% of PVs)

Compared with the spatial distribution of scenario BAU-0, CO_2 emissions are reduced in suburban areas and increased in the city center and around train stations in the case of compact city without technological mitigation measures (scenario Mit.-0). Under the scenarios with technological mitigation measures, 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) would increase due to the battery charge of EVs. As to the introduction of PVs, some or all of the electric power demand from each household could be covered by PV power generation.

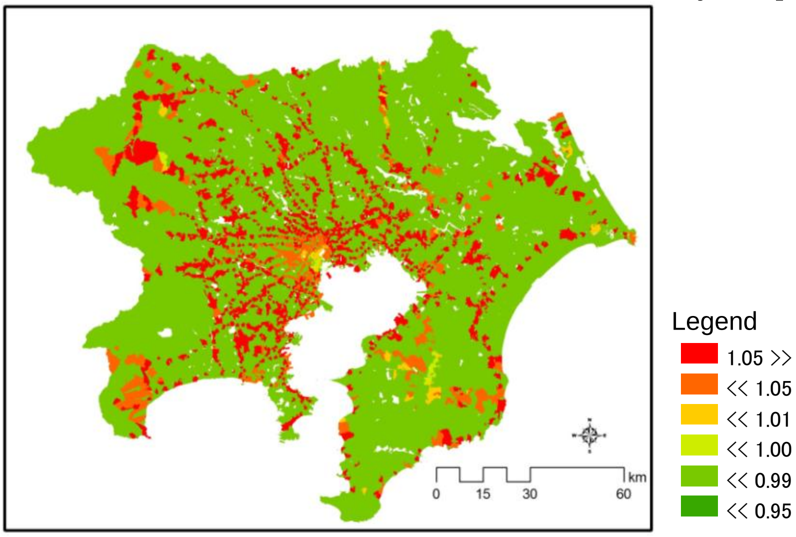


Figure 7. Comparison of population distribution (Mit. / BAU)

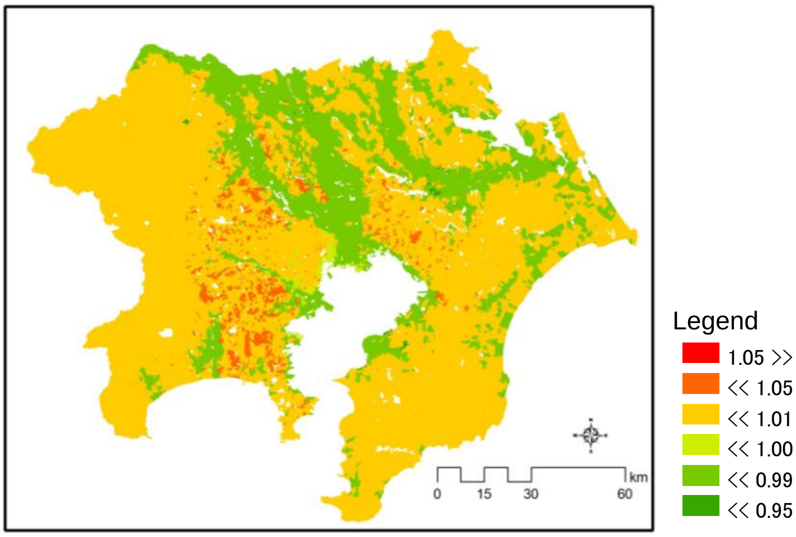


Figure 8. Comparison of population distribution (Ad. / BAU)

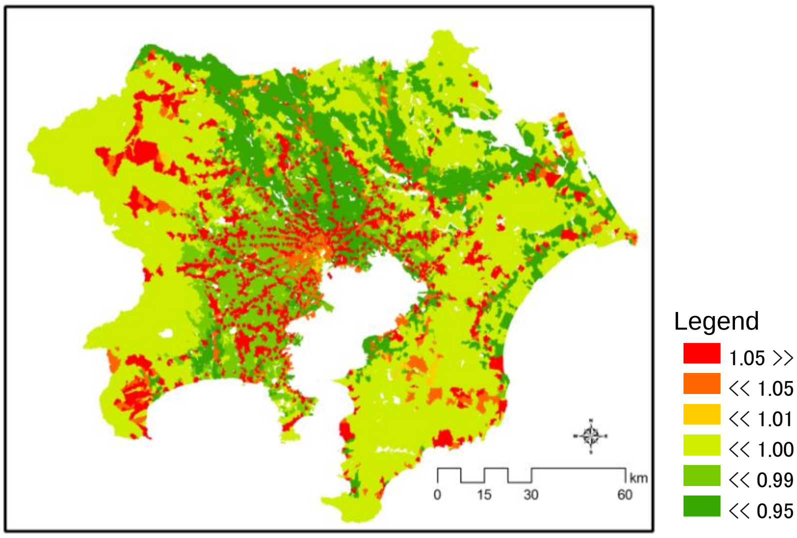


Figure 9. Comparison of population distribution ((Mit.+Ad.) / BAU)

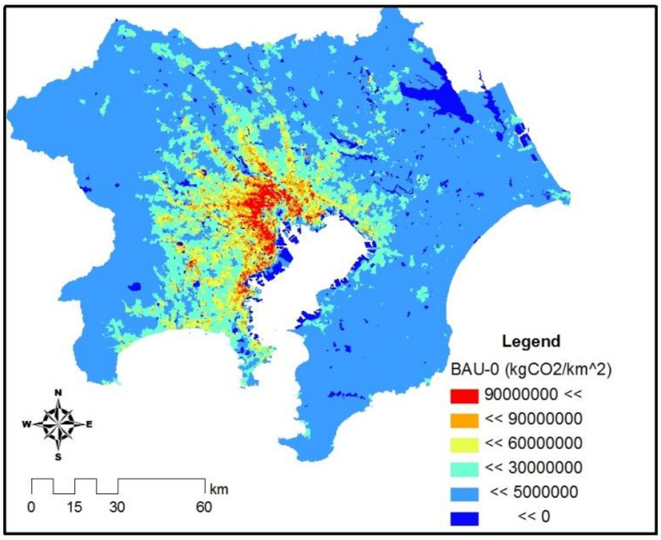


Figure 10. Direct and indirect CO_2 emissions of all households in the Tokyo Metropolitan Area (Scenario BAU-0: Dispersed city without technological mitigation measures, based on emission factor in 2011)

The indirect emissions in emission group 3 could be reduced because people would save electricity supplied by the electric power company. Compared with the case of compact city without technological mitigation measures (scenario Mit.-0), CO_2 emissions could be reduced in suburban areas where many detached houses would be located in the case of compact city with technological mitigation measures (the introduction of PVs and EVs) such as scenario Mit.-30. If the "adaptation by land-use" scenario was added, CO_2 emissions could not be reduced so much in some suburban areas which have a high liquefaction risk showed in Fig. 6. This is due to the fact that PV panels would be installed on the roofs of fewer detached houses depending on the decrease in the number of people living in flood-hazardous areas.

We have considered the population reduction of the Tokyo Metropolitan Area. Nevertheless, CO_2 emissions increase in the scenarios without the introduction of PVs and EVs (scenario BAU-0, Mit.-0, Ad.-0 and Mit.+Ad.-0). If Japan kept the CO_2 emission factors as equal to the one in 2011 and introduces PVs and EVs, the Tokyo Metropolitan Area could

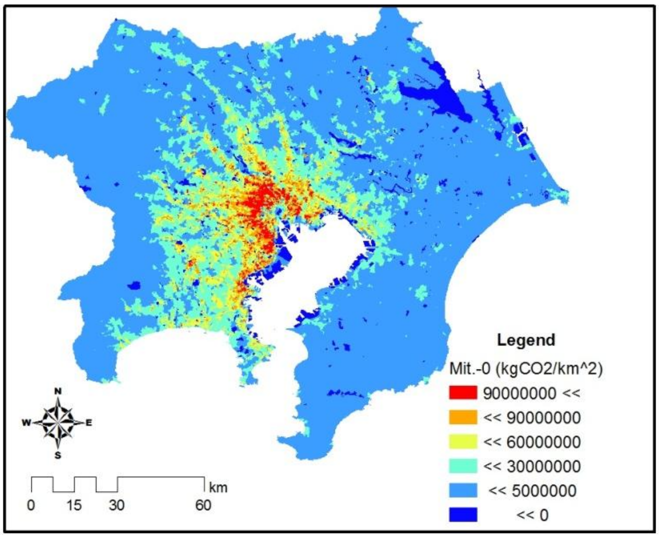


Figure 11. Direct and indirect CO_2 emissions of all households in the Tokyo Metropolitan Area (Scenario Mit.-0: Compact city without technological mitigation measures, based on emission factor in 2011)

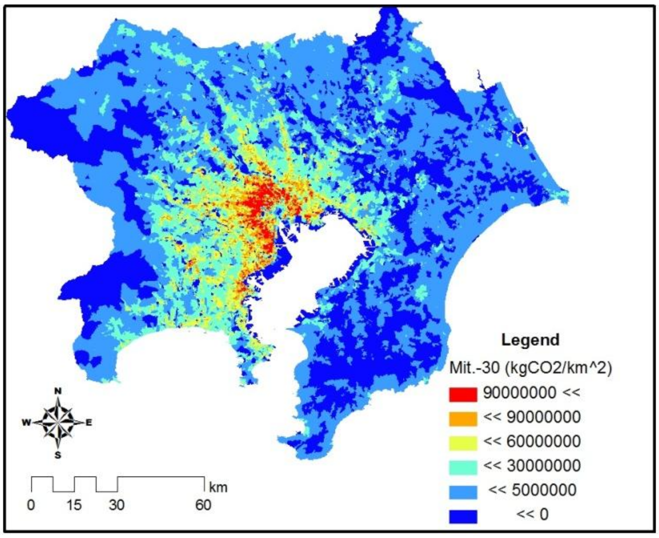


Figure 12. Direct and indirect CO_2 emissions of all households in the Tokyo Metropolitan Area (Scenario Mit.-30: Compact city with technological mitigation measures, based on emission factor in 2011)

achieve a CO_2 emission reduction of about 9-15%. However, if the emission factor increased as usual, the rate of CO_2 emission reduction might be only 6% even with the introduction of EVs and PVs (scenarios Mit.-20, Ad.-20 and Mit.+Ad.-20). The results indicate that the change of emission factor has a big impact on future CO_2 emissions.

Land-use scenarios considering climate change mitigation and adaptation are not sufficiently affected by the use of PVs and EVs. This is due to the fact that PV panels would 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 of climate mitigation and adaptation measures because the reduction rate by technological mitigation measures is very high. Therefore, simultaneous discussion of both mitigation and adaptation is meaningful.

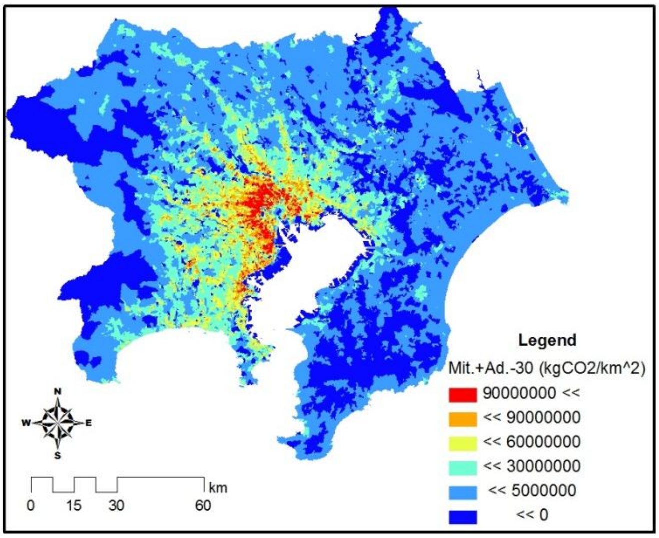


Figure 13. Direct and indirect CO_2 emissions of all households in the Tokyo Metropolitan Area (Scenario Mit.+Ad.-30: Compact city and flood risk prevention with technological mitigation measures, based on emission factor in 2011)

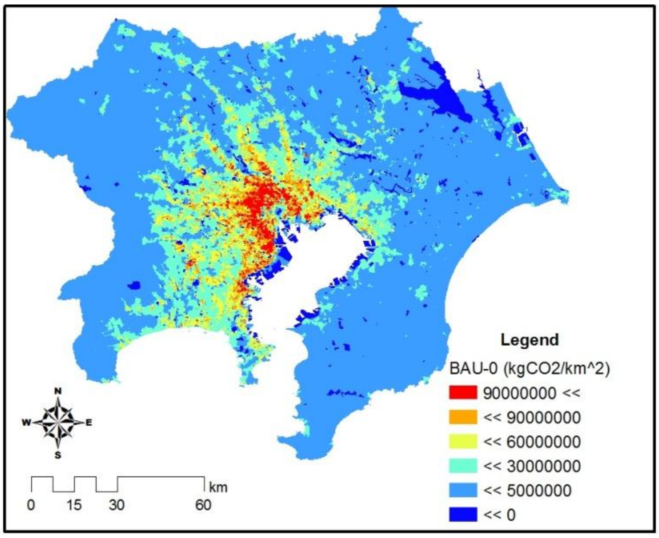


Figure 14. Direct and indirect CO_2 emissions of all households in the Tokyo Metropolitan Area (Scenario BAU-0: Dispersed city without technological mitigation measures, based on estimated emission factor for 2050)

5. CONCLUSION

This study estimated and evaluated CO_2 emissions corresponding to projected future emission factors by using our integrated evaluation model for land-use scenarios that consider compact cities and flood risk prevention as well as the introduction of EVs and PVs within the Tokyo Metropolitan Area. Furthermore, this study sought to evaluate both mitigation and adaptation measures focused on direct and indirect CO_2 emissions considering the impact of emission factor changes after the Tohoku Earthquake. A spatially explicit land-use model was used for building land-use scenarios, which had been based on real estate. A key point within this project was the definition of direct and indirect emissions from the viewpoint of the responsibilities of energy consumers and the consideration of emission factor change. As a result, we could show the future spatial distribution of CO_2 emissions by using this integrated evaluation system.

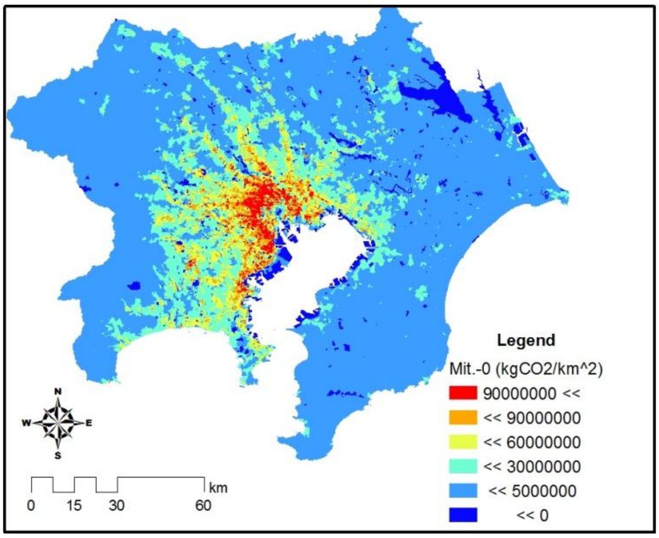


Figure 15. Direct and indirect CO_2 emissions of all households in the Tokyo Metropolitan Area
(Scenario Mit.-0: Compact city without technological mitigation measures,
based on estimated emission factor for 2050)

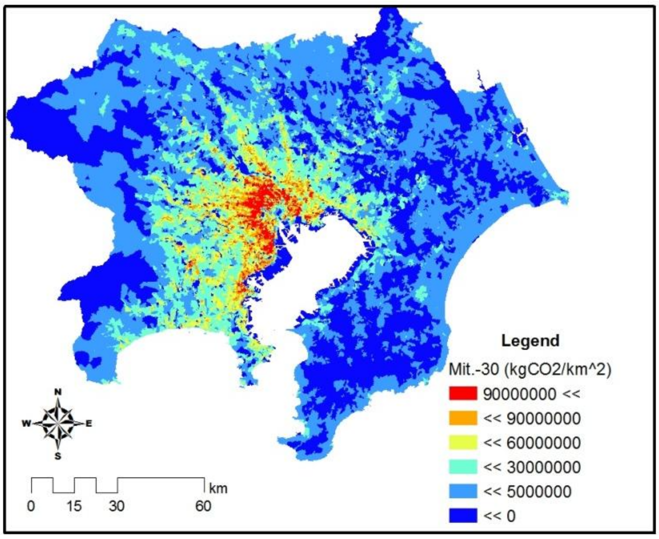


Figure 16. Direct and indirect CO_2 emissions of all households in the Tokyo Metropolitan Area
(Scenario Mit.-30: Compact city with technological mitigation measures,
based on estimated emission factor for 2050)

We could discuss the direct and indirect CO_2 emission evaluation in terms of the interaction between climate mitigation and adaptation measures for land-use scenarios. These evaluations were based on flood vulnerability assessments. We considered the co-relation between climate change mitigation and adaptation in the combination scenario case from the viewpoint of CO_2 emissions. The results suggest that climate change mitigation and adaptation can generate both a synergistic and trade-off effect from the viewpoint of CO_2 emissions. The reduction rate of scenario Mit.+Ad.-0 is little higher than that of scenarios Mit.-0 and Ad.-0, implying that mitigation and adaptation in terms of land-use scenario without the introduction of PVs and EVs are compatible. On the other hand, mitigation and adaptation 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. We have to find a strategy for compatibility between mitigation and

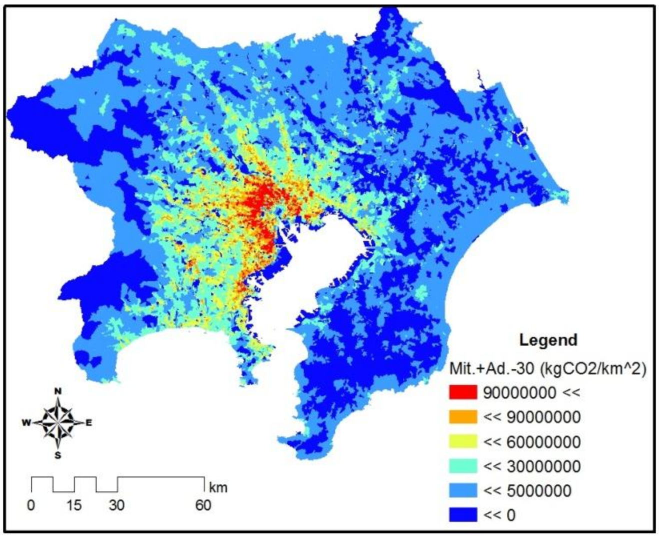


Figure 17. Direct and indirect CO_2 emissions of all households in the Tokyo Metropolitan Area (Scenario Mit.+Ad.-30: Compact city and flood risk prevention with technological mitigation measures, based on estimated emission factor in 2050)

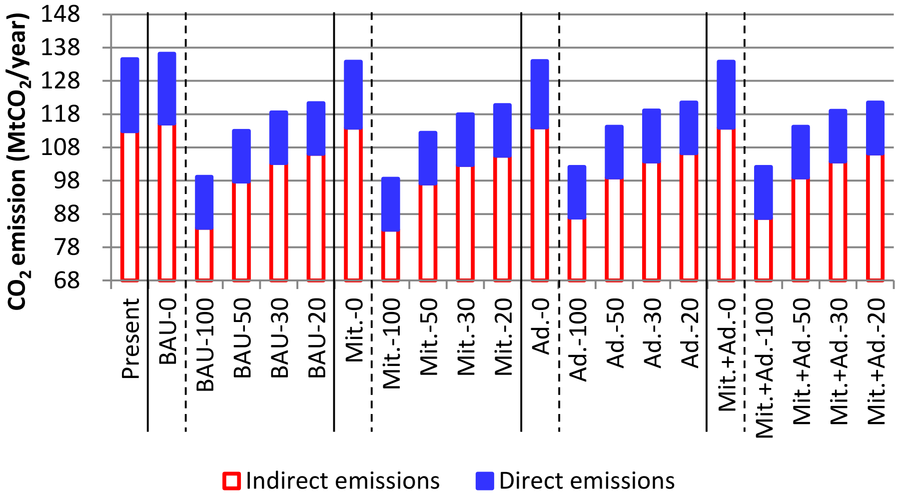


Figure 18. CO_2 emissions of all households under different scenarios (based on emission factor in 2011)

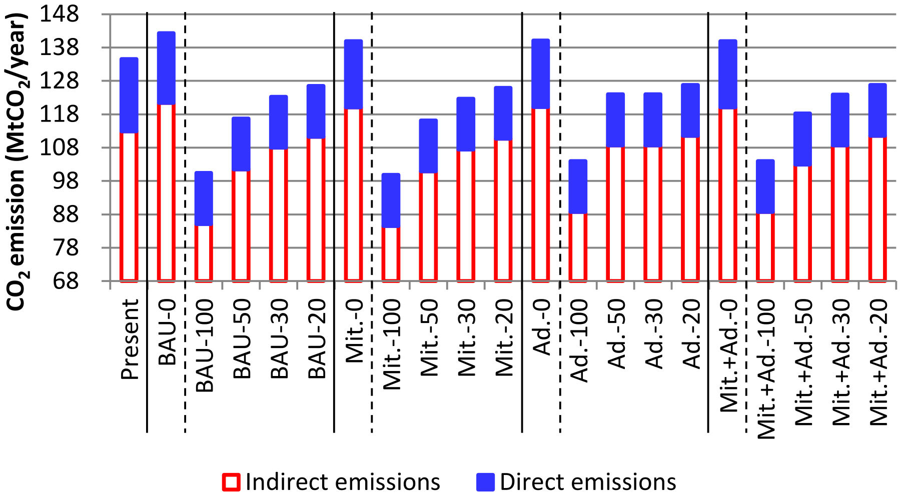


Figure 19. CO_2 emissions of all households under different scenarios (based on estimated emission factor for 2050)

adaptation using an evaluation system like this study. In the future, we should consider scenarios assuming the installation of PV panels on 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. As a result, the change of emission factor might have a big impact on future CO_2 emissions. It is indicated that not only the introduction and utilization of renewable energy but also the improvement of emission factor is important to realize CO_2 emission reduction. The results suggest that the diffusion of PVs is very important in the non-nuclear world to reduce CO_2 emissions, and that EVs still can contribute to CO_2 emission reduction despite the changes in emission factor. Also, compact urban form could effectively reduce CO_2 emissions.

Although we assumed an extreme diffusion rate of PVs and EVs for sensibility analysis, we should set a feasible rate in the future. As stated before, the Chugoku Bureau of Economy, Trade and Industry (2013) reported that the present diffusion rates of PV panels are just a couple of percent (Maximum: 9.0% in Saga Prefecture). The results of scenario 20 or 30 (i.e. diffusion rate of PVs: 20% or 30%) are moderate. As for EVs, we should simulate 50-75% of the diffusion rate in the future (Ministry of the Environment, 2012). Further studies and a careful observation of future policies and people's behavior are needed because tax cuts for eco-friendly cars have worked very effectively. We should also discuss a possible diffusion rate with local governments.

However, an intensive diffusion of PVs may raise another concern. The amount of power that can be generated by PV depends on the weather. An appropriate energy mix and the extension of the Energy Management System (EMS) using IT are essential for the mitigation of risks. It will involve additional costs like the maintenance of PV panels as well as initial costs. Mukai et al. (2011) have noted the systems' profitability, reliability, and failure risk in terms of sustainability. On the other hand, when PVs are installed intensively, the problem of reverse power flow may occur and technologies for storing electricity including vehicle to grid (V2G) must be further developed. However, the present paper did not consider such technological aspects.

It is necessary to consider the interchange of surplus electricity generated by PVs needs. Electric power interchange among household types with different living hours should also be considered, as pointed out by Taniguchi and Ochiai (2012). In this study, indirect emissions were estimated per year. 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 a potential risk of making services inefficient in the city and of increasing the costs 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 comprehensive climate change adaptation scenario, risk communication tools like those described by Burch et al. (2010) and resilience against multiple disasters including earthquake and tsunami are also important.

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