Urban Economics Model for Land-Use Planning

Yoshiki Yamagata, Hajime Seya and Daisuke Murakami

Abstract This chapter introduces our newly developed Spatially explicit Urban Land-use Model (SULM) as a tool for resilient urban planning. The SULM can create land-use and social economic scenarios at micro districts level based on an urban economic theory. In order to co-design transformative urban plans with local stake holders, it is important to visualize possible future land-use scenarios. This model makes it possible to endogenously project the residential choice of households, floor space and land area with considering location-specific disaster risk as well as economic and environmental factors. With this model, we can create scenarios for not only urban growth, but also urban shrinking, thus the method could be useful for both developing and developed countries' situations. In this study, the model was developed and calibrated for the Tokyo Metropolitan Area (Greater Tokyo) at the micro-district level (around 1 km grid) and used to simulate possible land-use scenarios with different urban forms. We have specifically looked at the implications for climate change mitigation and adaptation capacities. This chapter explains mainly the tested three land-use scenarios; (1) Business as usual scenario, (2) Extreme urban compact city scenario, and (3) Combined mitigation and adaptation scenario. The scenarios were assessed with multiple criteria including disaster/energy resilience and environmental sustainability (CO_2 emissions, urban climate) and economic benefits. The obtained results have shown that fairly large future economic costs could be saved by additionally considering adaptation (flood risk) in combination with mitigation (CO_2 emissions) in the scenario that we call "Wise Shrinking". Our research suggests that integration of resilience thinking into urban planning is important and promising.

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1 Introduction

One of the most important agendas that urban planners are facing in the coming decades is to establish new designs that actually improve the sustainability and resilience of cities responding to known and unknown risks. To support such planning, researchers can create possible future urban land-use scenarios. Then, in the process of co-designing with the local stakeholders, the scenarios can be evaluated in terms of environmental sustainability and human welfare. Such land-use scenarios may also help local policy makers to come up with effective urban policies (land use, transport, energy etc.) which would improve the urban sustainability and resilience.

Various attempts have been made in this direction (Al-Kodmany 1999; Nicholson-Cole 2005) considering natural hazard risks (Buchecker et al. 2013) and local climate change impacts (Schroth et al. 2015; Murakami et al. 2016). Especially, recent literature highlights the importance of considering trade-offs and co-benefits of climate change mitigation and adaptation measures (Larsen et al. 2012; Landauer et al. 2015). However, there are very few studies that have creates and tested landuse scenarios at the local level.

We have succeeded in creating a new model by employing the micro-economic urban modeling approach. The newly developed model is called Spatially explicit Urban Land-use Model (SULM) and it has been applied to several case studies in Tokyo Metropolitan area. This Greater Tokyo area is the largest mega-city in the world and the population in the area is 37 million and still growing though the whole national population has been decreasing since 2009.

In our series of case studies, we have been paying attention mainly to the implications of different spatial urban forms such as Compact and dispersed city scenarios. Using the model, we have simulated different urban forms incorporating expected changes from the current land use by different urban policies that influence residential locations. Actually, we have assumed several land-use and transport incentive policies that would induce substantial agglomeration or suburbanization. The created land-use scenarios with different urban forms were then tested against different sustainability and resilience criteria (Yamagata et al. 2013, 2015a; Yamagata and Seya 2013; Nakamichi et al. 2013; Adachi et al. 2014).

Yamagata et al. (2013) described the basic model structure and analyzed the implications of new land uses such as re-vegetation at the created open spaces in the Compact city scenario by comparing them with those of heavy suburbanization in the Dispersion scenario. Also, Yamagata and Seya (2013) simulated the distribution of spatial energy demand for Greater Tokyo in the future under Business As Usual (BAU) and Compact city scenario. In fact, Japanese urban planning has been actually shifted towards Compact city scenario due to “the Act on Special Measures Concerning Urban Renaissance”.

Nakamichi et al. (2013) focused on the implications of combining urban forms and technological changes by considering the wide deployment of Electric Vehicles (EV) and Photovoltaic Panels (PV), and simulated the impacts on CO_2 emissions from the residential sector. Adachi et al. (2014) simulated urban form impacts on urban climate using high resolution climate simulations with our land-use scenarios as their boundary condition. The results have shown that the re-vegetation in the Compact city scenario has a significant impact to mitigate the heat island effect and has a lot of adaptation values.

Especially, since the Great Tohoku Earthquake in 2011, we have been exploring effective ways to integrate different sustainability criteria from the resilience point of view in assessing a variety of urban forms. At this stage, our new integrated approach was not yet completely established, however in this chapter, we will elaborate our original urban design concept called “Wise shrinking”. This is a kind of extension of the Compact city scenario. The additional power of the “Wise shrinking” scenario manifested itself in constraining compaction which occurs only at places avoiding risk susceptible areas. Our analysis also has shown that the “Wise shrinking” concept could be successfully implemented as recently advocated “climate resilient” development where both climate mitigation and adaptation strategies are simultaneously achieved (Yamagata et al. 2013).

Our urban form scenarios and their assessment tool is supposed to be able to help urban planners. When they design compact urban plans in connection with climate policy, they can effectively combine Compact city (mitigation) policy and flooding risk management (adaptation) policy. Namely, by carefully considering the possible co-benefits and trade-offs between mitigation and adaptation strategies, climate resilient urban design would be achieved by “Wise shrinking”. In this chapter, we demonstrate such a possibility by modeling spatial complexity at the district level through actual case studies in Tokyo.

Firstly, we explain three land-use scenarios that have created and tested; (1) BAU scenario, (2) Compact city scenario (mitigation), and (3) “Wise shrinking” scenario which combines Compact city scenario and Resilience (adaptation) scenario that avoids flood risk areas for urban compaction. The results showed that the “Wise shrinking” scenario can additionally achieve a large economic benefit in achieving Compact city by inducing people to move to areas with less flooding risk. Then, the expected future damages due to floods can be decreased. In addition, we can also expect economic agglomeration effects from the newly created high density office and residential area in the Compact city scenario. In that case, the integration of climate change adaptation policy into Compact city policy could be implemented by financing the cost by the future revenue (mitigation of cost). If successfully managed, even during the process of shrinking, economic growth could be induced and the policy cost such as incentives could be compensated financially.

So, the “Wise shrinking” policy has a good economic rationale as a policy tool in aging societies with declining population like Japan. However, even though the “Wise shrinking” policy is beneficial to society in the long-run, there remains the difficulty that policy makers as well as local people, who would not like to change or move, usually find it difficult to support such policy, because it requires relatively large political and economic costs at the beginning. This is another reason why we call it "Wise shrinking" in the sense that we need to be wise enough to find a way to overcome the barrier. On the other hand, once actually implemented, the "Wise shrinking" scenario could improve urban resilience not only against flooding but also against all kinds of extreme events such as heatwaves. Furthermore, to illustrate a wide range of effectiveness, we also assess the scenarios in terms of various additional resilience criteria including energy, ecosystem and human well-being.

In fact, the Compact city scenario reduces the number of detached houses in the suburbs, so if the re-created open lands are vegetated, it would contribute to absorbing CO_2 and mitigating urban heat-island effect as well. The open space could also be used for mega-solar deployments which have a large potential to make the electricity production low-carbon and improve energy resilience in case of disasters. These varieties of urban form implications clearly demonstrate the importance of assessing both sustainability and resilience using indicators in the urban planning. The methods described in this chapter have been also applied and further discussed in the following Chaps. Modeling Urban Heatwave Risk in Adelaide, South Australia, Flood Risk Management in Cities and Land-Use Planning for Depopulating and Aging Society in Japan.

2 Model Structure

Following Yamagata et al. (2013), we explain about our model structure. The structure of our model is similar to the work by Ueda et al. (1995). It was originally inspired from the model by Anas (1982, 1984) and additionally implemented for the Japanese real estate market situation in which land and buildings are traded separately. The structure of our model is represented in Fig. 1. The model describes the behaviors of the three model agents; households, developers, and landlords, using variables such as spatial distribution of households, land rent, building rent, land demand and supply, building floor demand and supply. In this model, we excluded firm or business agents because it is difficult to model the choice behavior of firm location with high accuracy at the micro zone level. The model development is an ongoing project, at the moment, we also excluded transportation from the model because of data unavailability.

The major assumptions of our model are summarized as follows: (1) There exists a spatial economy whose coverage is divided into zones. (2) 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 the households and profit maximization by the developers and the absentee landlords. (3) The households are divided into seven categories shown in Table 1. (4) The total number of households (or population) in the metropolitan area is given (closed city). (5) The households choose their locations in accordance with indirect (maximized) utility and zone-specific attributes. (6) There is one residential land market and residential floor (building) market in each zone. These markets reach equilibrium simultaneously.

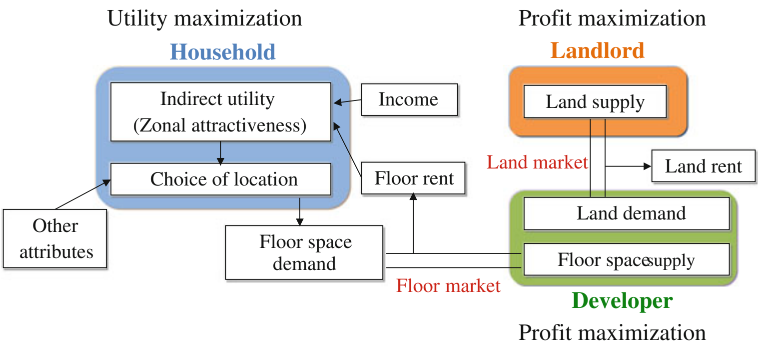

Fig. 1 The structure of SULM

Table 1 Household family type

Household family 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 with child(ren)
g. Other type

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. Also, the model can naturally deal with not only urban growth, but also urban shrinkage, which is becoming an important issue for developed countries confronting population decrease. Land-use equilibrium models are typically constructed using relatively large zones (e.g., municipality level) especially when one's study area is large. Our challenge was calibrating the model at the micro-district level (finely divided regions based on the seven-digit postcode, called cho-cho-moku in Japan) for the whole Tokyo Metropolitan Area. By doing so, we can look at the implications of district-scale Compact city policy such as the relaxation of the regulation on floor area ratio around train stations. The number of zones in our study area (the Tokyo Metropolitan Area) is 22,603. Regarding the notational explanations, please see Yamagata et al. (2013).

3 Creation of Urban Land-Use Scenario for the Year 2050

Using the model explained above, we have created three urban form scenarios for 2050: BAU (Dispersion city) scenario and two Compact city scenarios with and without Adaptation. In projecting the 2050 scenario, we have assumed that the

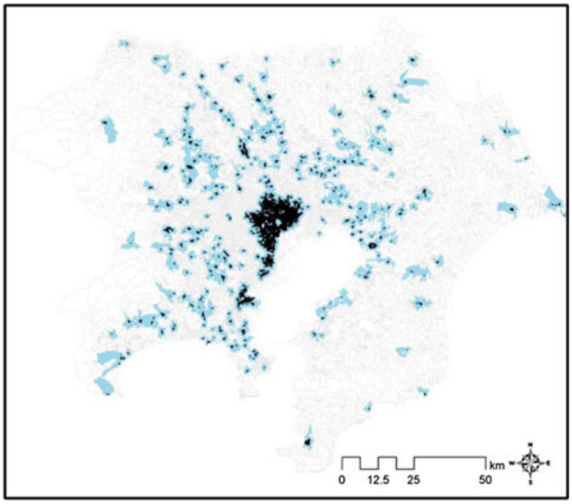

Fig. 2 Agglomerated office areas (*black*) and urban centers (*sky-blue*) (Color figure online)

number of each household type would change to (a): 2.07, (b): 1.07, (c): 1.39, (d): 0.66, (e): 0.69, (f): 1.32, (g): 0.85 (ratio to the number in 2005), which was estimated by log-linear extrapolation of estimates for the year 2030 produced by the National Institute of Population and Society Research, Japan. In the "Dispersion scenario", the total number of each household group is allocated based on the current share.

For the "Compact city scenario", the proximity of workplace to home is important for reducing trip length. Hence we quantified the degree of spatial agglomeration of office space using a spatial clustering technique (shown in black in Fig. 2), and defined the zones whose zonal distances were less than 500 m as *urban centers* (Yamagata et al. 2013). We subsidized these urban center zones by 1200 $/year (1$ = 100 yen), referring to the policy of Toyama city of Japan, which we call "Compact city scenario" in this study. For keeping the size of economy, we assumed that the total amount of income in the study area did not change among the scenarios. That is, the amount of subsidy is just cancelled out by the fixed property tax imposed on the other zones.

Compact urban form does not necessarily lead to the reduction of natural disaster risk. Hence we considered a scenario where only the zones whose average inundation depth was less than 5 m were subject to the subsidy, which we call "Combined scenario". In order to calculate inundation depth, we used the "possible inundation areas," designated and published by MLIT in around 2001 (Fig. 3) (available at: National Land Numerical Information download service, http://nlftp.mlit.go.jp/ksj-e/). The figure represents the areas which may be inundated by river flood.

Subsequent sections compare these scenarios in terms of disaster and energy resilience, CO_2 emissions, revegetation, and urban climate, respectively.

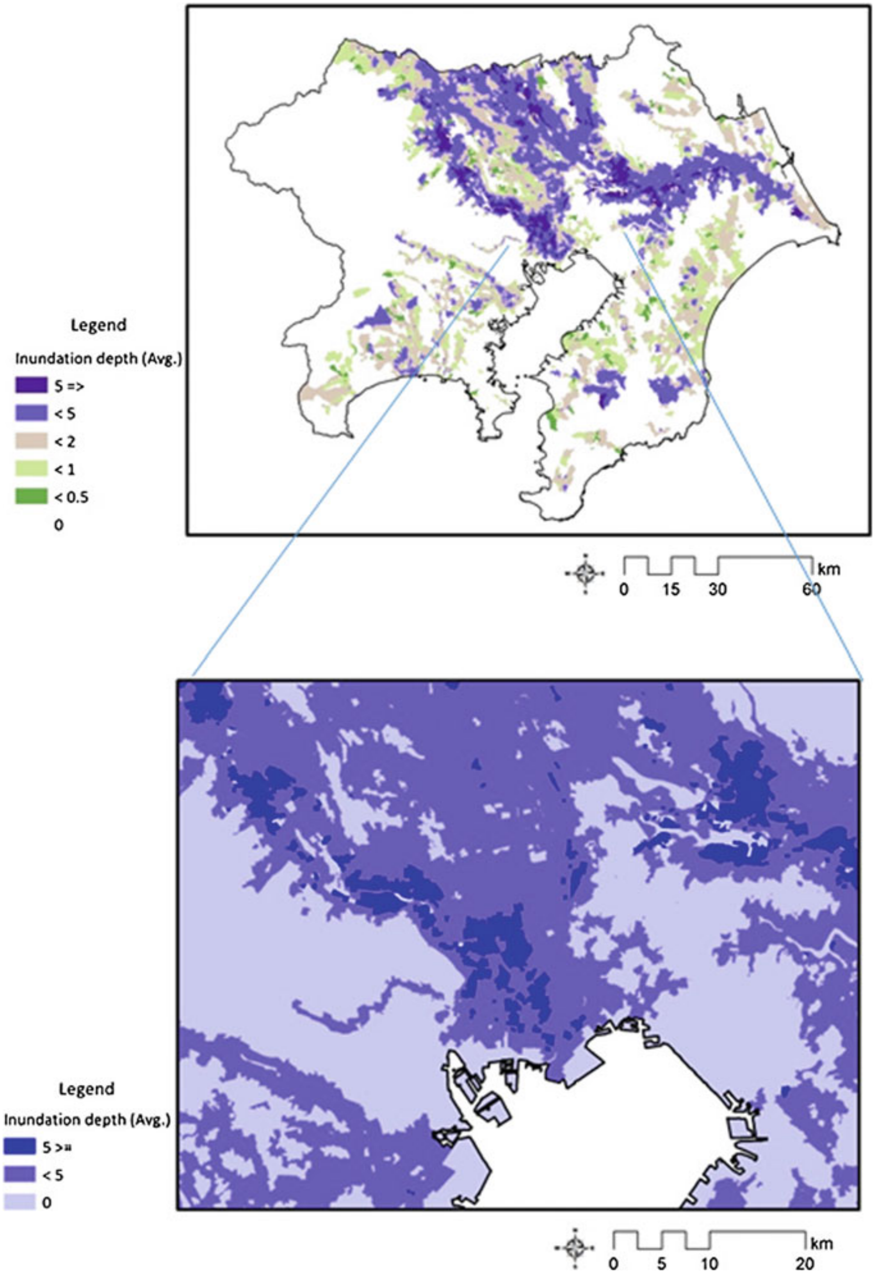

Fig. 3 Possible inundation areas (hazard map) of the Tokyo Metropolitan area

4 Disaster Risk Resilience: Economic Damages

For the economic evaluation of expected loss due to flood damages, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has prepared a flood control economy investigation manual (MLIT 2005). The losses of households (HH) compose damages to the house and furniture, are calculated as in Tezuka et al. (2013):

$$\begin{aligned} \textit{house damage} = & \textit{ house assetes} \times \textit{inundation area} \\ & \times \textit{damage rate by inundation depth}, \end{aligned} \tag{1}$$

$$\begin{aligned} \textit{furniture damage} = & \textit{ furniture assetes} \times \textit{inundation household} \\ & \times \textit{damage rate by inundation depth}. \end{aligned} \tag{2}$$

The house assets (yen/m^2) and furniture assets (yen/HH), and the damage rate by inundation depth is defined in MLIT (2005). The inundation area and depth are defined using the data shown in Fig. 3. Once house and furniture damage is calculated, it is multiplied by the return period, and transformed to the present value with a social discount rate of 4 %. The expected loss is calculated by summing it up to the next 50 years from the calibration year of 2005. In fact, to reflect the impacts from the climate change that should happen by the year 2015, it is necessary to evaluate the impact using downscaled climate change scenarios such as those that IPCC has created. In order to simplify the study focusing on urban forms, we did not consider climate risk change such as flooding risk in our study explained in this chapter. However, it is an important research topic for our future study.

Figure 4 represents the differences in projected population (left: Compact—BAU; right: Combined—BAU). In both scenarios, the population increased in urban centers. However, in the combined scenario, the population of high risk zones decreased as expected. The projected changes of expected flood damage under the Compact and Combined scenarios (compared to BAU scenario) are −7.2B$ and −30.4B$, respectively. This result suggests that a careful selection of subsidized area may lead to fairly big differences in expected loss.

Currently, many Japanese urban master plans mention the importance of Compact city as a “future vision” of the cities. However, as far as we know, few of them have the co-benefit viewpoint as our Combined scenario, but our results suggest the importance of the co-benefit viewpoint. In our study area, the Kinugawa River actually broke through a breakwater on September 10th, 2015 and Joso city, which is about 50 km north of Tokyo, was heavily damaged by huge flooding. The hazard map of Joso city clearly suggested the danger of this area, but flood risk was not capitalized into land prices and many households actually live in that area. Our empirical analysis in the future should be focused on such areas to help local governments in their decision making about urgent risk management.

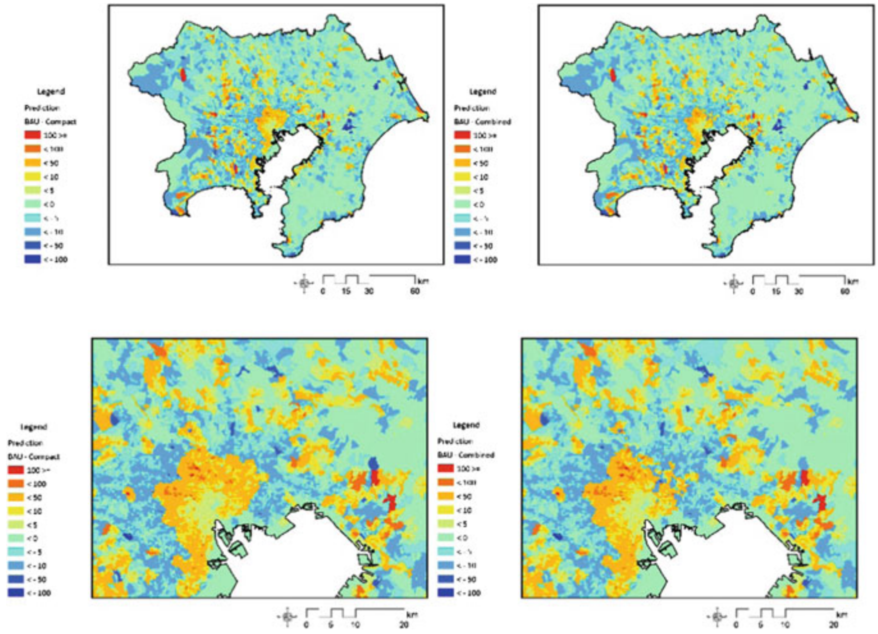

Fig. 4 Distribution of population in 2050 (*Left* compact—BAU; *Right* combined—BAU)

5 Disaster Risk Resilience: Affected People

Economic damage must be appropriately and accurately evaluated to design disaster prevention plans that would be necessary for risk management. Especially, the number of people affected must be estimated for the land-use regulations in hazardous areas, evacuation plan, placement of shelters, etc.

We have first estimated the number of people affected by inundation above floor level, by 2050. Specifically, the number of affected people in the i-th zone in s-th scenario, $p_{i,s}^{Fl}$, was estimated by the following equation.

$$p_{i,s}^{Fl} = p_{i,s} \times d_i^{Fl} \times \frac{(2050 - 2015)}{y_i^{Fl}}, \tag{3}$$

where $p_{i,s}$ is the total population in the i-th zone in s-th scenario, d_i^{Fl} is the probability of suffering from a flood with a depth of more than 0.5 m pear year,[1] and y_i^{Fl} is the return period of the flood (source: National Land Numerical Information download service).

We have also quantified the population affected by major earthquakes, $p_{i,s}^{Eq}$, using

[1]0.5 m has often been assumed as the floorboard height.

$$p_{i,s}^{Eq} = p_{i,s} \times d_i^{Eq} \times \frac{(2050 - 2015)}{30}, \tag{4}$$

where d_i^{Eq} is the occurrence probability of more than one earthquake whose seismic intensity exceeds 6.5 [Fig. 5; source: Japan Seismic Hazard Information Station (National Research Institute for Earth Science and Disaster Prevention)].

Figures 6 and 7 display the difference between the affected population in BAU scenario and those in the Compact/Wise shrinking scenario. These figures show that in the Compact city scenario the number of affected people increased in the central area, in which many people are concentrated. Actually, in the Compact city scenario the number of people affected by floods increased by 1617, whereas the number of people suffering from earthquakes increased by 147. This result suggests that city compaction, which ignores disaster resilience, can inflate disaster risks.

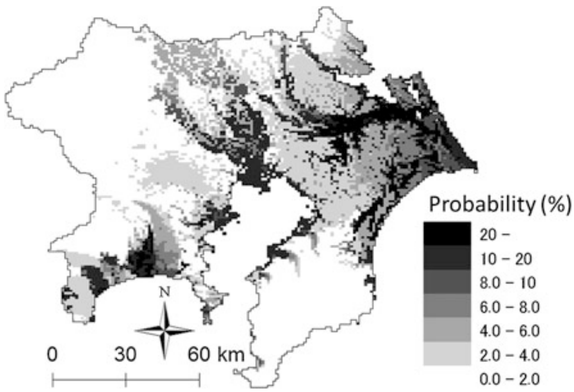

Fig. 5 Occurrence probability of earthquakes whose seismic intensity exceeds 6.5, within 30 years

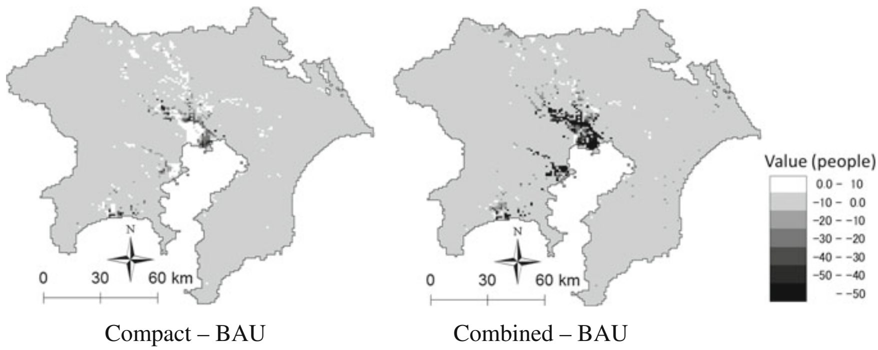

Fig. 6 Differences in population in areas with an inundation depth of more than 0.5 m. The population increases in the white zones whereas it decreases in the *black* zones

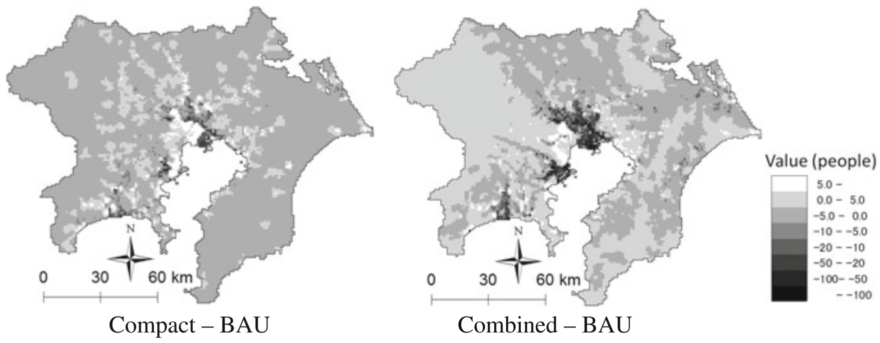

Fig. 7 Differences in the expected number of people who suffer from earthquakes whose seismic intensity is more than 6.5 by 2050

By contrast, the combined scenario decreased both of these risks in the central area. In total, the number of people suffering from floods decreased by 23,996, and those affected by earthquakes decreased by 11,978. The combined scenario makes cities compact while mitigates influences of disasters on people.

6 Energy Resilience

Urban form is a key driver determining energy demand and supply. This section introduces SULM by Yamagata and Seya (2013) for a comparison of the aforementioned scenarios in terms of energy resilience.

We first estimated PV (Photovoltaics) electricity demands and supplies. Then, we estimated the hourly electricity supply in each month using an equation proposed by Yokoi et al. (2010):

$$PV_i = I \times \tau \times L_i^{PV} \times \eta pc \times Kpt \times T. \tag{5}$$

where I is the monthly total irradiance (source: METPV-2 database (New Energy and Industrial Technology Development Organization)), τ is the array conversion efficiency (=0.1), L_i^{PV} is the area for PV panel installation, ηpc is the running efficiency of power conditioner (=0.95), Kpt is the temperature correction coefficient which is 0.92221 from May to October, and 1.00 for the other months. L_i^{PV} is estimated using the following equation:

$$L_i^{PV} = L_i \times \xi \times \iota \times 1/\cos\psi, \tag{6}$$

where L_i is the building land estimated in each scenario by SLUM, ζ is the building-to-land ratio, ι is the possible area of installation on the roof (=0.3), and ψ is the optimal angle of inclination (=30°).

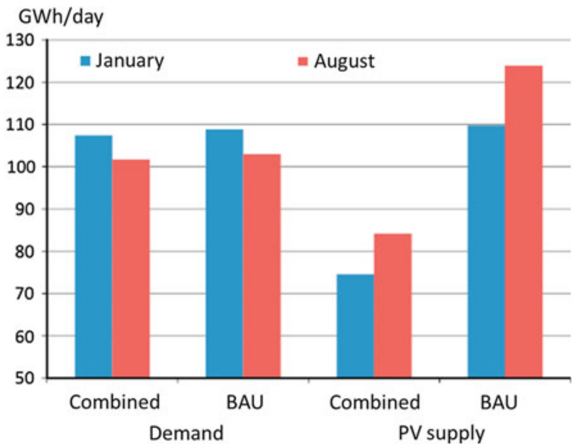

Fig. 8 Daily electricity demand and PV supply. *Source* Yamagata and Seya (2013)

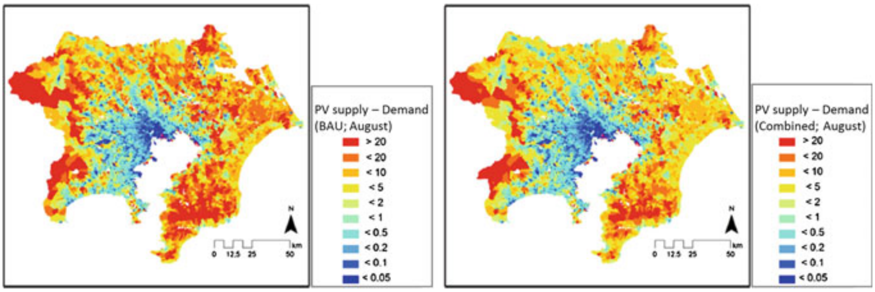

Fig. 9 Electricity demand and PV supply as the ratio of demand in August (*Left* BAU; *right* combined). *Source* Yamagata and Seya (2013)

Concerning the electricity demand, we calculated monthly demand in the i-th zone by multiplying the flood area, which was estimated using SULM under each scenario, and monthly basic unit consumption per floor area, which was published by The Japan Institute of Energy (2008).

Figure 8 shows the estimated total energy demand and supply in August in the BAU and combined scenarios. While electricity demands are similar between these scenarios, PV supply in the combined scenario is significantly smaller than that in the BAU scenario. This is because the combined scenario reduces residential building land, L_i, in suburban and/or high-risk areas. To achieve an urban computation while keeping energy resilience, it would be important to discuss how to ensure lands for PV panels.

Figure 9 maps the difference between electricity demand and supply in each zone in August. This figure demonstrates that PV electricity supply cannot cover the electricity demand in the central area in either the BAU or the combined scenario. To increase energy resilience, efficient energy use would be important in the central area.

Fortunately, city compaction allows us to implement efficient smart grids and community heating and cooling systems with low cost (OECD 2012). Integration of the Compact city scenario with the community level energy sharing system would be a very effective strategy in terms of energy resilience (see, Yamagata et al. 2015b).

7 CO_2 Emissions

Reduction of CO_2 emissions is a central issue toward climate change mitigation. Nakamichi et al. (2013) applied scenarios established by SULM to project the lifecycle of CO_2 from household sectors using the following equation:

$$CE_i = \sum_j H_{i,j}\left[\sum_k E_{i,j,k}(ic_{i,k} + dc_{i,k})\right], \quad (7)$$

where CE_i is the annual CO_2 emission in zone i, $H_{i,j}$ is the number of households with type of j in that zone (see, Table 1), $E_{i,j,k}$ is the annual expenditure on the k-th item by j-th household in the i-th zone, $ic_{i,k}$ and $dc_{i,k}$ are indirect and direct CO_2 emission intensities for the k-th item. The items include Food, Housing, Fuel, and so on. The annual expenditure of each item, $E_{i,j,k}$, was calculated based on the Household Expenditure Survey in Japan, and the emission intensities were based on Embodied Energy and Emission Intensity Data for Japan (National Institute for Environmental Studies).

The number of households $H_{i,j}$ was estimated using SULM under the BAU, Compact, and combined scenarios. Besides, to assess trade-offs/synergies between city compaction and use of renewable energy, the authors combined these scenarios with a scenario of PV (photovoltaic panels) and EVs (electric vehicles) dissemination. Specifically, they assumed the dissemination scenarios summarized in Table 2. In each scenario, CO_2 emission reductions by PVs and EVs were estimated by replacing emissions from fuel consumption of gasoline cars with indirect emissions from EVs. PVs were assumed to be installed on the roof tops of detached houses based on Eqs. (5) and (6), where L_i^{PV} is scaled based on the assumption in each scenario. EVs are installed by replacing gasoline cars in each zone following the dissemination rates.

Table 2 Dissemination scenarios of EVs and PVs. *Source* Nakamichi et al. (2013)

Scenarios of EVs and PVs	Dissemination rate of EVs (%)	Dissemination rate of PVs (%)
0	0	0
100	100	100
50	100	50
30	100	30
20	100	20

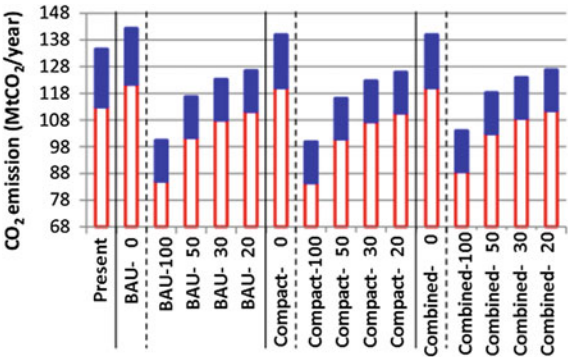

Fig. 10 CO_2 emissions of all households under different scenarios. *Source* Nakamichi et al. (2013)

Figure 10 summarizes the estimated total direct and indirect CO_2 emissions from households. BAU-x denotes BAU scenarios whose scenarios of EVs/PVs are x (see, Table 2). This figure suggests that PVs and EVs effectively reduce CO_2 emissions; in each of BAU, Compact, and combined scenarios, CO_2 emissions when PVs/EVs are fully installed (100 %) are about half of CO_2 emissions when they are not installed (0 %). Unfortunately, at each dissemination rate, the CO_2 emissions in the compact and combined scenarios are on average slightly larger than those in the BAU scenarios. This is because Compact or Combined scenarios imply a smaller number of detached houses. Thus, it would be important to explore how to achieve city compaction and CO_2 emission reduction at the same time.

8 Revegetation

This section estimates how much the Compact and the Combined scenarios contribute to revegetation, based on building land areas L_i given in each scenario. To examine it, we first modeled the composition of land uses using land attributes by employing a compositional data model (see, Pawlowsky-Glahn and Buccianti 2011). This model describes $l_{i,d}$, which is the composition of d-th land-use ($d \in \{1, 2,\ldots, D\}$) in zone i using Eqs. (8) and (9):

$$l^*_{i,d \neq D} = \log\left(\frac{l_{i,d \neq D}}{l_{i,D}}\right) \tag{8}$$

$$l^*_{i,d \neq D} = \sum_p x_{i,p}\beta_p + u_i \tag{9}$$

where $x_{i,p}$ is the p-th explanatory variable, β_p is the coefficient, u_i is a disturbance. In this model, Eq. (8) transforms $l_{i,d}$ to $l^*_{i,d}$ to eliminate the constant sum constraint (i.e., the sum of compositions must be constant). Equation (9) quantifies the impacts of the explanatory variables (see, Table 3) on $l^*_{i,d}$.

Table 3 Explanatory variables for the compositional model

Variables	Source	Variables	Source
Log of population density	MIC[a]	Dummy of alluvial fun	NIED[c]
Mean elevation	MLIT[b]	Dummy of natural levee	
Distance to the nearest railway station		Dummy of back marsh	
Distance to the nearest primary river		Dummy of delta	
Road density		Dummy of sandbar	
Dummy of urbanization control area			
Dummy of lake			

[a]MIC: Ministry of international affairs and communications, Japan
[b]MLIT: Ministry of land, infrastructure, transport and tourism, Japan
[c]NIED: National research institute for earth science and disaster prevention

The model is estimated by fitting it with the land-use composition data in 1997 [source: National Land Numerical Information (MLIT)] whose categories include paddy field, other agricultural land, forest, wildland, building land, other land (e.g., roads), and river/lake. Specifically, Eqs. (8) and (9) are fitted for each land-use type except for building land that we assume as the base land use, D (i.e., 6 models are estimated separately).

Table 4 summarizes the estimated coefficients. The coefficients in the d-th model are positive if a unit increase of $x_{i,p}$ attracts $l_{i,d}$ rather than the base land use, $l_{i,D}$ (building land), and negative vice versa. For example, the negative coefficients of lnPop for each land-use type suggest that lnPop attracts building lands rather than any other land uses; and, the negative coefficient of Avg_Elv for paddy fields suggests that paddy fields tend to be located in lower elevation areas than building lands, whereas the positive coefficients for other agricultural land, forest, wildland, and water show that they tend to be in higher elevation areas. Overall, the signs of the estimated coefficients are intuitively reasonable.

Based on the obtained model, we have estimated how much building areas are converted to green areas (paddy field, other agricultural land, and forest) in the scenarios. Figure 11 shows the estimated revegetation. Because of the depopulation, a certain level of revegetation occurred even in BAU. The Compact city scenario indicates a very similar revegetation pattern with BAU. In other words, this scenario does not necessarily effectively increase green areas. On the other hand, green areas significantly increase in the combined scenario, especially in the north and eastern areas. As a result of the revegetation in the city, future climate change risks such as heat wave and flush flooding are also expected to be reduced significantly as well as the river flooding risk. These are several multiple important benefits of the combined scenario.

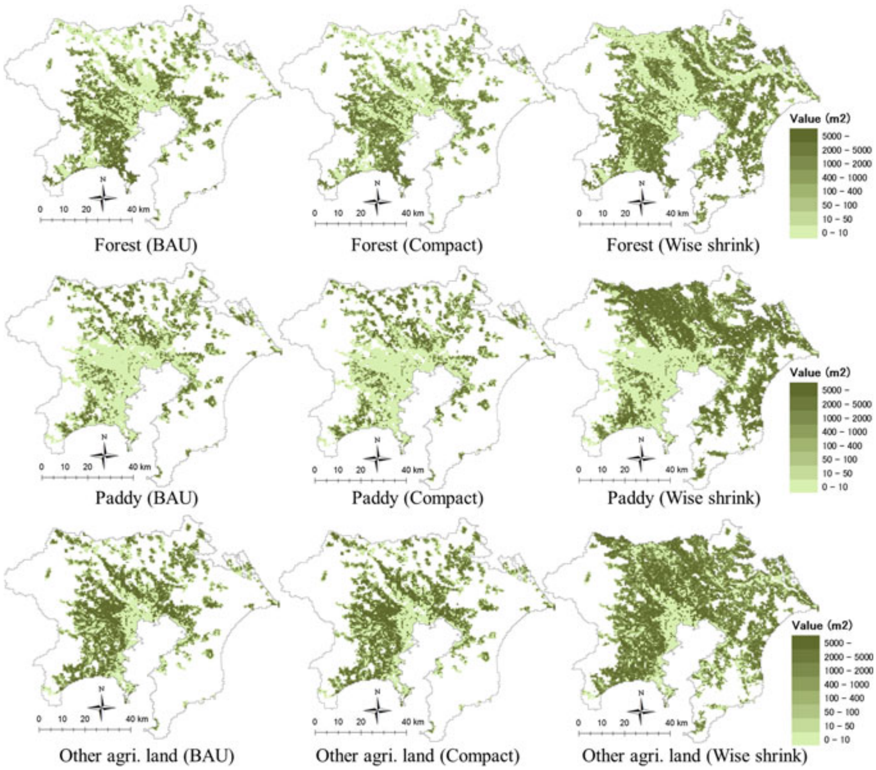

Fig. 11 Estimated revegetation in 2050

9 Urban Climate: Influence on the Urban Heat Island

Urban form determines the intensity of urban heat island. Adachi et al. (2014) quantified the influences of the BAU and the combined scenarios for urban heat island. Specifically, distribution of population, total floor area, and building area in these scenarios were used as inputs of the Weather Research and Forecasting model (WRF; Skamarock and Klemp 2008), and the influences of these scenarios on future heat island were estimated.

Figure 12 shows the change in nighttime temperature brought by the modification of the urban form. In the BAU scenario, temperatures in suburbs are increased because of the urban expansion. This tendency is significant in the eastern area, which is currently less urbanized, and projected to be urbanized in BAU. In contrast, in the combined scenario, because of the urban compaction, the suburban temperatures are decreased. On average, the temperatures in the combined scenario are roughly 0.2° lower than those in the BAU scenario.

Table 4 Estimation results (spatial compositional data model)

	Paddy	Agricultural	Forest	Wild	Other land	Water
Const	3.28***[a]	2.54***	6.45***	−0.46*	−2.05***	−1.24***
lnPOP	−0.76***	−0.09***	−0.96***	−1.03***	−0.34***	−0.94***
Avg_Elv	−0.01***	0.00***	0.01***	0.00***	0.00***	0.00***
Dist_Sta	0.26***	0.10***	−0.07***	−0.09***	−0.23***	−0.14***
Dist_River	0.06***	−0.02***	0.07***	0.03***	−0.02***	0.02***
Den_Road	−0.47***	−0.46***	−0.30***	−0.13***	0.16***	−0.11***
D_UCA	0.12	0.06	0.18*	0.19	0.02	−0.51***
D_Lake	−2.14**	−3.67***	−1.96**	−0.66	0.20	10.01***
D_AF	3.71***	−0.14	−6.74***	−2.53***	0.08	3.92***
D_NL	3.51***	−1.92***	−7.95***	−1.99***	−0.93***	6.08***
D_BM	4.49***	−2.90***	−7.70***	−1.92***	−0.62***	2.84***
D_Delta	2.45***	−3.47***	−6.27***	−1.70***	−1.45***	3.39***
D_SB	0.67**	−1.07***	−4.38***	−2.13***	−0.17	0.69*
Adj_R2	0.47	0.30	0.71	0.39	0.07	0.29

[a] *, **, and *** denote statistical significance whose levels are 10, 5, 1, and 0.1 %, respectively

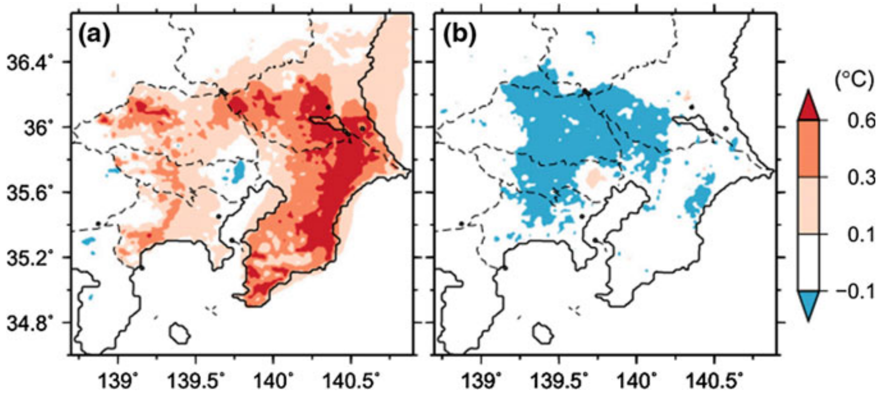

Fig. 12 The difference in monthly nighttime surface air temperature between 1:00 and 5:00 JST in August 2010 between the real situation and **a** the BAU scenario and **b** the combined scenario. *Source* Adachi et al. (2014)

10 Conclusion and Outlook

This study assessed the co-benefits of a mitigation measure (Compact city policy) and an adaptation measure (retreat from high flood hazard areas) from the view point of disaster and energy resilience, and other factors characterizing sustainability. We showed an example of effective Compact city policy which attains co-benefits with the adaptation measure. That is, our results suggest that if we carefully choose the subsidized area, we can mitigate fairly big expected loss due to the flood damage.

We also demonstrated that, while the combined scenario significantly increases green areas and mitigates the urban heat-island, it lowers the energy resilience. These results suggest the importance of considering trade-offs and synergies among factors determining resilience and sustainability in urban planning.

We found some similar attempts for Paris (Viguié and Hallegatte 2012; Viguié et al. 2014; Masson et al. 2014), which are based on urban economic model. Comparing our approach and theirs theoretically and/or empirically is an interesting next topic.

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