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Developing Urban Adaptation Strategies for Global Warming by Using Data Mining Techniques: A Case Study of Major Metropolitan Areas in Japan

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1. Introduction

Modern life and high population density is the main characteristics of cities. Urbanization diffuses all over the world in recent centuries. Metropolitan areas are formed to provide more industrial production as well as business communication. Furthermore, economies of scale arising from spatial concentration of activity within industries in metropolitan area, i.e. industry agglomeration (Rosenthal & Strange, 2001); population, resources, capital concentrate into the cities. Industry agglomeration makes cities more adaptive to uncertainty of business environment (Strange et al., 2006). Hence the most profit seems to be created in metropolitan area in this globalization age. Nonetheless, natural resources are rapidly produced into goods, consumed and transformed into side-products, e.g., solid waste and a variety of pollutants, into the environment. Besides, more and more infrastructures are developed in the progress of civilization, but only a few natural habitats are preserved, leading to the decreases of biodiversity (van Bohemen, 1998; Mcdonald et al, 2008). Though people have convenient life in metropolitan area, however, the urbanization is bringing about a great deal of critical global environmental changes. In particular, the enhanced global warming, due to the urban growth, is threatening the human security and the possibly irreversible changes on ecological systems in a variety of dimensions and scales (Chung et al., 2009; Firman et al., 2011; Kataoka et al., 2009; Khasnis & Nettleman, 2005; Robert & Cory, 2003). Thereby, it is imperative for the municipalities to develop adaptation strategies for metropolitans in the context of human security, urban sustainability and urban growth. In the progress of making urban growth policies, important factors should be taken into consideration from the socio-economic, environmental, cultural, public health and ecological perspectives regarding the potential threats of global warming.

Several types of environmental indicators are developed to diagnose the current situation and formulate adaptation strategies against the global warming and associated issues of urban sustainability. Normally, recent studies argued that the urban sustainability should take the composite system ecology into consideration, implying that the interactions of the stakeholders in the city have to be considered in the evaluation simultaneously (Mistch, 2003; Roseland, 1997). Also, several evaluation bases could be used to examine the performance of the environment system, e.g. the energy, monetary, material bases (Weng & Fujiwara, 2011). A variety of environmental impact assessment tools, e.g., life-cycle assessment (LCA), life-cycle cost (LCC) assessment and cost-benefit analysis (CBA), could serve as efficient evaluation methods in the evaluation of countermeasures against the global warming, given that credible parameters are available (Jeong & Lee, 2009). In fact urban environment is a socio-economic-natural composite ecological system such that public policies should consider all the dimensions simultaneously, reorganizing the urban system into ecological network both for human system and natural system. Some attempts have developed the Environmental Kuznets Curve (EKC) to analyze the relationships between the economic and environmental quality, regarding driving factors of income, consumption and policy interventions (Arrow et al., 1995; Azomahou et al, 2006; Magnani, 2000; Weng et al., 2010). Although more and more evidences showed that the EKCs explain the relationships of several environmental pollutants, including the CO_2 emission, some methodological issues of EKC have to be dealt with from the perspective of statistics (Müller-Fürstenbergera & Wagner, 2007). One reason is that the available socio-economic and environmental data is not sufficient. Meanwhile, as for the conventional environmental evaluation methods, the data availability would lead to the uncertainty of the quantification outcomes, limiting the credibility of the interpretations. Hence, the dimensionless composite environmental indicators could be an alternative tool for environmental evaluation. For this purpose, the pressure-status-response (PSR) framework was established by the Organisation for Economic Co-operation and Development [OECD] in 1993 to serve as an environmental policy evaluation tool (OECD, 1993) and afterward, the driving forces are adopted as driving forces-state-response (DSR) framework in 1996 (OECD, 1996). Also, Kessler and Van Dorp (1998) proposed the adoption of environmental indicators under a strategic environment assessment (SEA) framework, in which socio-economic and environmental variables should be considered simultaneously. Subsequently, a driving forces-pressure-state-impact-response (DPSIR) framework was proposed by European Environmental Agency [EEA] as an extension of the PSR (EEA, 1999). Based on the aforementioned frameworks, Hu and Wang (1998) argued the urban environment should be considered as a socio-economic-natural composite ecological system; they adopted economic, cultural, environmental, and infrastructure variables to simulate the linkages among the functional modules in the evaluation of the performance of eco-reconstructing of eco-villages in China. Button (2002) proposed an analytical indicator framework composed evaluating urban environmental system; the indicators are composed of economic, environmental, social, cultural, and political variables. Jago-on et al. (2009) analyzed the critical urban environmental issues by using the DPSIR framework and proposed countermeasures for Asian cities. Regarding global warming, Omann et al. (2009) conducted a DPSIR analysis discussing the impacts of the climate changes on the biodiversity conservation. The outcomes indicated that the driving forces from the modern human society, e.g., the socio-economic and cultural attributes and the energy demands of transportation, bring about significant negative impacts on the global warming and the related challenges of biodiversity conservation. Also, Rounsevell et al. (2010) proposed a conceptual DPSIR framework qualitatively analyzing the apparent driving factors of socio-ecological indicators and their influences on the eco-services. A normal evaluation scheme is proposed in the study arguing that the attributes and the influencing time-spatial scales of the driving factors should be clarified, and thus possible quantitative impact analyses and efficient countermeasures could be subsequently implemented.

Regarding the quantification of indicator systems, Song et al. (2004) developed a hierarchical indicator system to evaluate the ecological sustainability of inshore cities in China. In their study, many socio-economic and environmental variables are categorized into three functional groups: structure, function, and coordination. Variables were linked as an ecological network, and the sustainability of each city was calculated and compared by a composite evaluating indicator. In addition, Srebotnjak (2007) presented a quantitative indicator system developing an integrated environmental performance index. She also particularly argued the importance of the development and the utilization of credible environmental statistics while the data availability is the main problem in environmental evaluations. Furthermore, Pan & Kao (2009) developed an inter-generation equity indicator (IGEI) to quantify the sustainability among generations in recent decades at a world scale, under a pressure–state–response (PSR) framework.

In fact, local actions are of particular importance in the enhancement of sustainability regarding the urbanization. In this sense, this study aims at developing a precautionary indicator system (PIS), which is in aid of the formation of adaptation strategies of the global warming mitigation. After the World War II, Japan made great economic development in the past six decades. Some regionally nuclear cities have been formed all over Japan. However, the current deficiencies of policies and future adaptation strategies are expected to deal with facing the critical challenges of sustainable development, e.g., the urban growth management and the global warming mitigation. In this study, by evaluating current social, economic, and environmental system of urban area, the precautionary indicators are developed to diagnose the current situation. Finally, strategies for developing a sustainable city are proposed in the final part.

2. Research approach

In order to deal with the information hidden in an enormous amount of statistics, data mining approaches are rapidly developed in recent decades. Mainly, data mining approaches are based on the integration of statistical theories for pattern recognition, causal relationships development, behavior analysis and system control & forecasting. In particular, several methods show superiority for the purpose of data mining, including regression analysis, multivariate analysis, indicator system techniques, artificial neural network, and data envelope analysis (Chen et al., 2010; Ngai et al., 2009). Moreover, the developing information system technologies, e.g., the geographic information systems and the remote sensing technology, provide high quality data and platforms for data analysis and integration.

The aforementioned approaches could be applied to establish the precautionary indicator system of global warming from a variety of perspectives. In developing a precautionary indicator system of global warming, several principles should be taken into consideration in constructing a practicable and informative indicator system (Duke & Aull-Hyde, 2002; Niemeijer, 2002; Solnes, 2003; Valentin & Spangenberg; 2000; Verdoodt & Van Ranst, 2006):

- The indicator system should have sufficient rational theoretical bases;
- The boundary of the indicator system should be identified clearly for the purpose of nature hazard mitigation;
- Credible and consistent databases should be available to support the calculation of the indicator system;

- The interpretations of the indicator system should be direct and informative for all the stakeholders, e.g. policy-makers and citizens.

Some PSR- or DPISR-like indicators have been established in the aforementioned literature. Each indicator system has its specific application purpose and respective data requirement at different scales. Based on the above principles, a modified DPSIR framework is considered in this study to develop a representative precautionary indicator system. Thereby the research flow of this study is represented in Fig. 1.

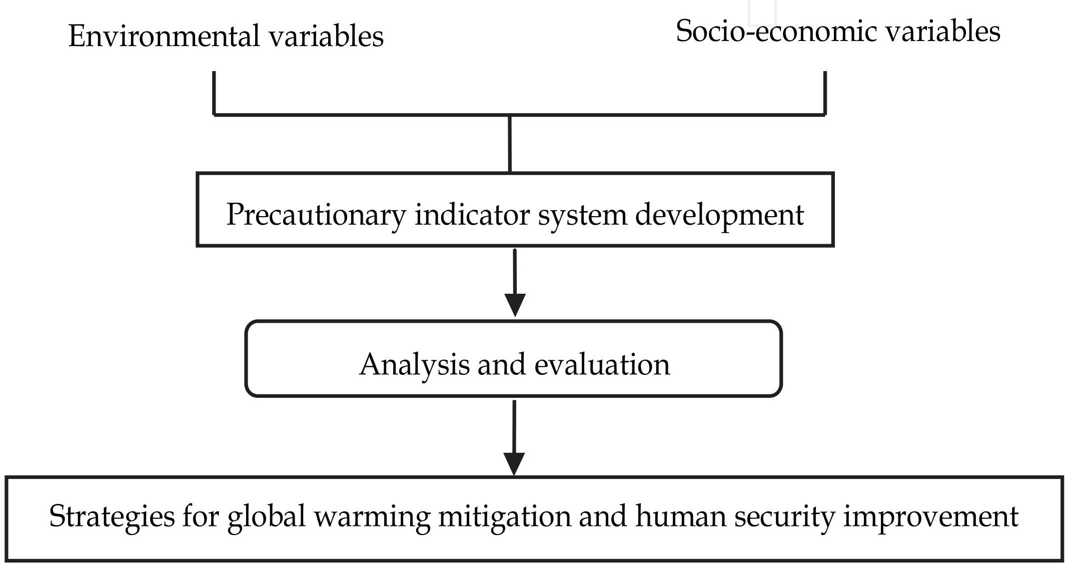

Fig. 1. The research flow diagram of this study.

To meet the goal of reflecting the urban adaptation mechanisms in terms of global warming, a three-layer hierarchical indictor system is induced to develop an evaluating indicator framework. A composite urban system is divided into three levels of indicators, and finally an overall score is estimated. The levels are decided by considering to the urban socio-ecological networks using socio-economic and environmental variables, which serve as the fundmental components of the indicator system. The variables are linked as a composite socio-economic and ecological network, representing the levels of the urban growth and the sustainability. According to the definition of Tanguay et al. (2008), the terms in the statistics are identified as variables, and an indicator means composite information obtained from specific variables.

The PSR analytical framework in this study is composed of three categories- "Pressure and State," "Function" and "Coordination." In addition, the driving factors and the responses are emphasized within the flows among the components. By such manipulation, a composite urban social-economic-natural system could be described by the intrinsic relationships among the components and the flows, on the basis of system ecology, as shown in Fig. 2.

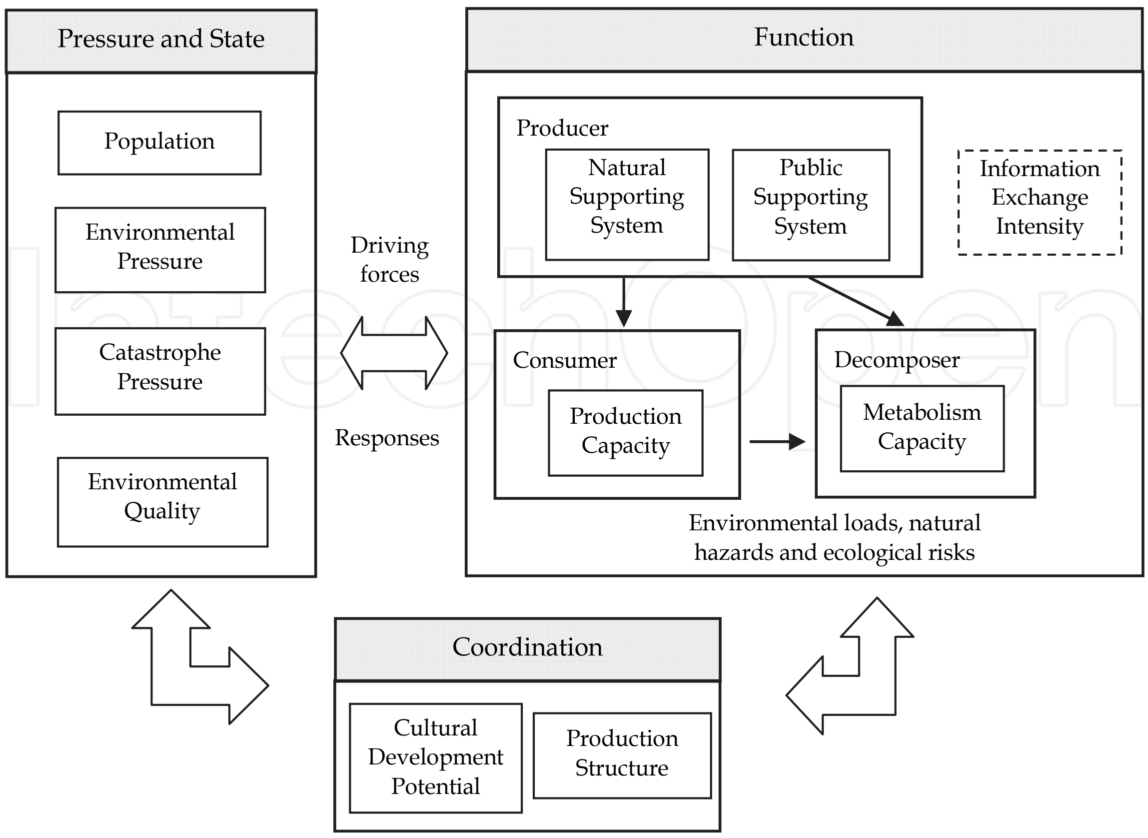

Fig. 2. The conceptual framework of the precautionary indicator system towards a sustainable city.

The characteristics of the intrinsic relationships of the precautionary indicator system are designed on the basis of the system ecology thinking and the research purpose. Some points of view are assumed in the framework as follows:

- The indicator system is to represent the intrinsic interactions of the socio-economic-environment systems, implying that all the sub-systems are integrated by rationally choosing the variables and determining the indicators' weights.
- Each 1st-level indicator is composed of several 2nd-level indicators, which represent the intrinsic properties. Each 2nd -level indicator is composed of some significant 3rd-level indicators, which are specifically selected to represent the characteristics of the upper level indicator, considering the data availability.
- The first 1st-level indicator, "Pressure and State," reflects the current pressure levels on the social, environmental and ecological states. This category reflects the quality and pressures of an urban system. Also, some available natural hazard variables would be highlighted and linked to other common environmental variables.
- The second 1st-level indicator, "Function", denotes the main socio-ecological network in an urban system. Like biological food-web, "Producer" in an urban system is assumed as "Natural Supporting System" and "Public Supporting System". They provide the resource for both social society and biosphere. "Consumer" in an urban system is assumed as "Production Capacity" representing the efficiency of the production sectors. "Decomposer" in an urban system is assumed as the "Metabolism Capacity", which means the efficiency and performance of environmental loads treatment. Finally, the linkages of socio-environmental-ecological networks are

assumed to be highly affected by the "Information Exchange Intensity" in this study. In each 2nd -level indicator, some representative variables are selected as well.

- In principle, the stronger the producer and decomposer are, the more robust an ecological system would be. That is, the production sectors could be transformed into a sustainable manner and the environmental quality could thus be self-regulated at an optimal level through the intrinsic mechanisms. Thereby, a powerful natural supporting sub-system and metabolism sub-system means that the potential of self-resiliency would be large, and the environmental quality and human security can be promoted. In this category, the social security indicators are particularly emphasized regarding the human security.
- The third 1st-level indicator, "Coordination," denotes the future potential indicator of ecologically sustainable city. The importance of the culture and the industrial structure are stressed herein.
- It is assumed that the driving forces are imposed and the responses are exchanged interactively among the main parts.
- Each 3rd-level indicator is given an attribute in the calculation procedure. A larger value of the 3rd-level indicator represents that the city has a better sustainable quality with regard to this indicator, and thus the attribute is positive; otherwise, it is negative. This attribute is determined by the domain knowledge of social and natural science.

In this study, the aggregation procedures of the precautionary indicator system are proposed as follows:

1. Normalize the values of each 3rd-level indicator using the following equations.
   - If the variable is a positive driving indicator (i.e. the larger value of original variable denotes a higher level of the urban sustainability):

$$Q_{i_{3rd-level},j} = \frac{C_{i_{3rd-level},j} - \overline{C}_{i_{3rd-level}}}{S_{C_{i_{3rd-level}}}} \quad \forall i,j \tag{1}$$

where $Q_{i_{3rd-level},j}$ is the normalized score of the i item of the 3rd-level variable in j region; $C_{i_{3rd-level},j}$, $\overline{C}_{i_{3rd-level}}$ and $S_{C_{i_{3rd-level}}}$ are the original value of the i item of the 3rd-level variable in j region, its average and its standard error, respectively.

   - If the variable is a negative driving indicator (i.e. the larger value of the original variable denotes a lower level of the urban sustainability):

$$Q_{i_{3rd-level},j} = -\left(\frac{C_{i_{3rd-level},j} - \overline{C}_{i_{3rd-level}}}{S_{C_{i_{3rd-level}}}}\right) \quad \forall i,j \tag{2}$$

2. Aggregate the upper level indicator by the weighted aggregation, the formula is:

$$Q_{m,j} = \sum_i W_i \times Q_{i,j} \quad \forall m,i,j \tag{3}$$

where W_i is the weight of each lower level indicator; $Q_{m,j}$ denotes the value of the m upper-level indicator of in j region, and $Q_{i,j}$ is the value of the i lower-level indicator in j region.

After implementing the normalization transformation, the values of each 3rd-level indicator would obey a standard normal distribution, with a zero average and an unity standard error. Thus, all the indicators could be compared at the same scale. After the articulation, a larger normalized value of the indicator would imply the region is relatively more ecologically sustainable among the regions of interest with respect to the indicator.

The aggregation indicator is calculated by weighted summation. In terms of the determination of the weight of each indicator, expert consultation (i.e., the Delphi Method), analytical hierarchical procedure (AHP), analytical network procedure (ANP) and principal component analysis (PCA), could be considered (Hsu et al., 2010; Solnes, 2003; Song et al., 2004; Srebotnjak, 2007). Moreover, the nonlinear fuzzy theory could be introduced into the aforementioned methods. In this study the weight of each indicator is determined based on the outcomes of Song et al. (2004) and adjusted by the author according to the research purpose. In this sense, some variables associated with the global warming would be highlighted in the precautionary indicator system. In principle, the larger weight means the indicator with the higher degree of global warming.

3. Data and results

Japan has experienced the processes of extensive industrialization and urbanization, and now attempts to construct a sustainable society with particular focuses on the development of low-carbon society, material-cycle society and symbiotic society. In order to achieve the aforementioned objectives and to deal with the potential deficiencies, the adaptation strategies of the metropolitan areas are necessary. For this reason, 18 major cities in Japan are selected as the study areas to prepare required and feasible policy measures from a comprehensive perspective. In this sense, the official statistics of socio-economic and environmental variables in 2008 are utilized to develop the precautionary indicator system (Yokohama City Government, 2011). The structure of the precautionary indicator system is constructed according to the principles discussed in Section 2 and data availability. 30 representive variables are particularly selected in the indicator system, and the detailed definitions and the values of the variables are provided in Table 1 and Table 2, respectively.

In fact, it is difficult and tricky to select appropriate variables. In addition, the measurement bases, such as the measure of area or capita, would have important implications. In this study, normally, per capita variables are often used in constructing the socio-economic relationships while area-specific variables are preferred in establishing the natural-ecological-environmental relationships. Still, some particular considerations are imposed for several variables considering the complex interactions. For instance, this study adopts the spatial density of college students to reflect the degree of the potential on research and regional development. Furthermore, no variables are selected as the adequate industrial structure while the attributes and expectations may vary by regions.

Using the cross-section data in 2008 as shown in the Table 2, the calculation of the indicator system is implemented hierarchically. First, each 3rd-level indicators are calculated using Eq. (1) and Eq. (2), and the results are also shown in Table 2; secondly, the 2nd-level indicators and the 1st-level ones are estimated by Eq. (3), sequentially. Consequently, the overall score of each city can be obtained. A comparative analysis is performed based on the outcomes.

The 1st-level indicator	Weight	The 2nd-level indicator	Weight	The 3rd-level indicator	Description	Primative unit	Weight	Attribute of the original variable
Pressure and State	0.6	Population Scale	0.15	The population density	The indicator is regarded as the driving force of urban resources consumption and environment pollution.	10^3 capita/km^2	0.4	-
				The population natural growth rate	The indicator reflects the population sustainability.	‰	0.3	+
				The household density	The indicator is regarded as the driving force of urban resources consumption and environment pollution.	household/km^2	0.3	-
		Environmental Pressure	0.2	Per capita electricity consumed	The indicator is regarded as the environmental pressure in the urban system.	kWh/day	0.2	-
				Per capita water consumed	The indicator is regarded as the environmental pressure in the urban system.	m^3/yr	0.2	-
				Per capita natural gas consumed	The indicator is regarded as the environmental pressure in the urban system.	10^5 MJ/yr	0.15	-
				Per capita general waste generated	The indicator is regarded as the environmental pressure in the urban system.	kg/day	0.15	-
				The spatial car density	The indicator is regarded as the environmental pressure in the urban system.	number/km^2	0.15	-
				The ratio of road in total area	The indicator is regarded as the heat island effect and ecological habitat fragment in the urban system.	%	0.15	-
		Catastrophe Pressure	0.5	The maximum daily rainfall	The indicator is regarded as the risk indicator for the climate change due to global warming.	mm/day	0.5	-
				The maximum daily temperature	The indicator is regarded as the risk indicator for the climate change due to global warming.	℃	0.15	-
				Crimes incidents intensity	The indicator attempts to reflect the social safety pressure in the urban system.	cases/10^3capita	0.15	-
				Fire accident intensity	The indicator attempts to reflect the social safety pressure in the urban system.	cases/10^3capita	0.2	-
		Environmental Quality	0.15	Ambient Photochemical oxidant concentration	The indicator is regarded as the environmental response to the human activities and the regarded as the current environmental quality.	ppm	0.33	-
				Ambient NOx concentration	The indicator is regarded as the environmental response to the human activities and the regarded as the current environmental quality.	ppm	0.33	
				Ambient PM concentration	The indicator is regarded as the environmental response to the human activities and the regarded as the current environmental quality.	ppm	0.33	-

Table 1. The structure of the precautionary indicator system in this study.
Note: The unit denotes that of the original variable.

The 1st-level indicator	Weight	The 2nd-level indicator	Weight	The 3rd-level indicator	Description	Primative unit	Weight	Attribute of the original variable
Function	0.3	Production Capacity	0.1	Per capita income	The indicator is regarded as the intensity of production and consumption in urban system though only the one year lag data is available.	10⁴￥(2008 prices)/yr	1	+
		Natural Supporting System	0.35	The annual rainfall	The indicator is regarded as the resource abundance for the natural ecological system.	mm	0.2	+
				The ratio of natural surfaces within the total area	Natural surfaces denote urban parks, forests, vegetation fields and lakes. The indicator is regarded as the resource abundance for urban environment metabolism, ecological habitats development and natural functions operation.	%	0.8	+
		Public Supporting System	0.15	The spatial availability of hospital bed	The indicator represents the capacity of public health care.	number/km^2	0.15	+
				The spatial availability of doctors	The indicator represents the capacity of public health care.	number/km^2	0.3	+
				Crime clearance rate	The indicator implies the efficiency of social safety system	%	0.25	+
				The spatial availability of disaster assistance	The indicator is regarded as the efficiency of social safety system.	cases/km^2	0.3	+
		Information Exchange Intensity	0.2	The spatial intensity of fixed phone and mobile phone services registered	The indicator is regarded as the efficiency of information exchange flow.	number/km^2	0.5	+
				The spatial intensity of internet service registered	The indicator reflects the efficiency of information exchange flow.	number/km^2	0.5	+
		Metabolism Capacity	0.2	Sewage prevailing rate	The indicator is regarded as the capacity of urban environment metabolism.	%	0.5	+
				The recycling ratio of general waste	The indicator is regarded as the capacity of urban environment metabolism.	%	0.5	+
Coordination	0.1	Civilization Development Potential	1	The ratio in the municipal expenditure on education	The indicator is regarded as the administrative support for civic education and cultural preservation.	%	0.5	+
				The density of college students	The indicator is regarded as the potential for regional development.	number/km^2	0.3	+
				The spatial intensity of museums, libraries, natural and cultural heritage appointed	The indicator is regarded as the resource abundance for cultural development.	number/km^2	0.2	+

Table 1. The structure of the precautionary indicator system in this study. (*conti.*)
Note: The unit denotes that of the original variable.

Variable \ City	Sapporo	Sendai	Saitama	Chiba	Tokyo (special wards)	Kawasaki	Yokohama	Niigata	Shizuoka	Hamamatsu	Nagoya	Kyoto	Osaka	Sakai	Kobe	Hiroshima	Kitakyushu	Fukuoka
The population density (10^3 capita/km^2)	1. 693 (0.709)	1 .308 (0.803)	5.521 (-0.226)	3 .481 (0.272)	14.046 (-2.310)	9.631 (-1.231)	8.394 (-0.929)	1.118 (0.850)	0.511 (0.998)	0.538 (0.991)	6.886 (-0.560)	1.772 (0.690)	1.193 (-1.793)	5.574 (-0.239)	2. 773 (0.445)	1.289 (0.808)	2.019 (0.629)	4.215 (0.093)
The population natural growth rate (‰)	0.30 (-0.431)	2.50 (0.992)	2.40 (0.928)	2.00 (0.669)	0.40 (-0.367)	4.10 (2.028)	1.90 (0.604)	-0.50 (-0.949)	-1.3 (-1.467)	0.80 (-0.108)	0.90 (-0.043)	- 0.70 (-1.079)	- 0.50 (-0.949)	1.10 (0.086)	- 0.30 (-0.820)	2.30 (0.863)	- 1.00 (-1.273)	3.00 (1.316)
The household density (number/km^2)	783.45 (0.659)	575.14 (0.764)	2,284.94 (-0.095)	1,448.92 (0.325)	7,008.77 (-2.469)	4,438.23 (-1.177)	3,582.28 (-0.747)	421.50 (0.841)	195.82 (0.954)	209.58 (0.947)	3,062.58 (-0.486)	810.80 (0.645)	5,800.22 (-1.862)	2,427.58 (-0.167)	1,207.35 (0.446)	572.92 (0.765)	872.69 (0.614)	2,007.32 (0.044)
Per capita electricity consumed (kWh/day)	4,854.18 (0.520)	6,248.44 (0.114)	6,855.80 (-0.063)	10,603.46 (-1.154)	7,161.74 (-0.152)	6,594.90 (0.013)	6,558.47 (0.024)	5,727.29 (0.266)	7,425.71 (-0.229)	6,725.81 (-0.025)	17,011.74 (-3.020)	2,796.31 (1.119)	2,951.33 (1.074)	2,417.32 (1.230)	2,512.08 (1.202)	5,779.90 (0.251)	8,737.47 (-0.610)	8,574.22 (-0.563)
Per capita water consumed (m^3/yr)	93.03 (1.532)	110.18 (0.328)	106.29 (0.602)	100.50 (1.008)	126.21 (-0.797)	110.11 (0.334)	109.59 (0.370)	125.25 (-0.729)	123.60 (-0.613)	102.62 (0.859)	123.28 (-0.591)	121.28 (-0.451)	155.19 (-2.831)	113.06 (0.126)	118.81 (-0.277)	122.29 (-0.521)	108.99 (0.412)	97.20 (1.240)
Per capita natural gas consumed (10^5 MJ/yr)	69.97 (1.026)	110.26 (0.648)	89.10 (0.847)	455.50 (-2.596)	235.034 (-0.525)	379.868 (-1.886)	138.11 (0.386)	153.46 (0.242)	133.56 (0.429)	55.15 (1.166)	159.84 (0.182)	170.54 (0.081)	259.76 (-0.757)	272.70 (-0.879)	190.24 (-0.104)	138.51 (0.382)	118.55 (0.570)	95.34 (0.788)
Per capita general waste generated (kg/day)	1.08 (-0.096)	1.03 (0.191)	1.03 (0.208)	1.08 (-0.123)	1.11 (-0.326)	0.90 (1.083)	0.83 (1.550)	1.13 (-0.441)	1.08 (-0.096)	0.96 (0.682)	0.91 (1.028)	1.09 (-0.173)	1.43 (-2.434)	1.06 (-0.016)	1.09 (-0.184)	0.88 (1.194)	1.07 (-0.029)	1.37 (-2.018)
The spatial car density (number/km^2)	884.33 (0.769)	757.59 (0.865)	2,549.93 (-0.489)	1,746.95 (0.118)	4,221.22 (-1.752)	3,229.92 (-1.003)	3,337.07 (-1.084)	779.73 (0.849)	339.66 (1.181)	403.52 (1.133)	3,838.11 (-1.462)	728.04 (0.888)	3,850.18 (-1.471)	2,518.65 (-0.465)	1,142.98 (0.574)	710.12 (0.901)	1,175.30 (0.550)	2,037.04 (-0.101)
The ratio of roads in total area (%)	0.0033 (-0.597)	0.0028 (-0.150)	0.0019 (0.541)	0.0025 (0.092)	0.0011 (1.154)	0.0012 (1.112)	0.0015 (0.836)	0.0051 (-2.060)	0.0031 (-0.430)	0.0057 (-2.555)	0.0025 (0.093)	0.0017 (0.715)	0.0015 (0.851)	0.0020 (0.449)	0.0023 (0.201)	0.0026 (0.002)	0.0034 (-0.664)	0.0021 (0.409)
The maximum daily rainfall (mm)	37.5 (1.581)	87.5 (-0.157)	111.5 (-0.992)	83.5 (-0.018)	111.5 (-0.992)	78.5 (0.156)	78.5 (0.156)	65.5 (0.608)	125.5 (-1.479)	103 (-0.697)	133.5 (-1.757)	118 (-1.218)	57 (0.903)	57 (0.903)	47 (1.251)	50.5 (1.129)	65.5 (0.608)	82.5 (0.016)
The maximum daily temperature (℃)	31.4 (2.641)	33.6 (1.277)	37.3 (-1.016)	35.3 (0.224)	35.3 (0.224)	35 (0.410)	35 (0.410)	34.8 (0.534)	36 (-0.210)	36.6 (-0.582)	37.9 (-1.388)	37.7 (-1.264)	36.4 (-0.458)	36.4 (-0.458)	34.7 (0.596)	36.7 (-0.644)	34.5 (0.720)	37.3 (-1.016)
Crimes incidents intensity (cases/10^3capita)	15.34 (0.481)	14.21 (0.689)	17.79 (0.026)	19.59 (-0.305)	17.56 (0.069)	12.69 (0.970)	12.28 (1.046)	13.40 (0.839)	11.94 (1.109)	12.21 (1.058)	26.27 (-1.541)	22.46 (-0.837)	31.14 (-2.441)	21.37 (-0.636)	18.69 (-0.140)	13.17 (0.880)	20.34 (-0.445)	22.39 (-0.823)
Fire accident intensity (cases/10^3capita)	0.38 (-0.179)	0.35 (0.115)	0.34 (0.294)	0.33 (0.395)	0.48 (-1.180)	0.33 (0.366)	0.30 (0.698)	0.19 (1.764)	0.33 (0.385)	0.40 (-0.362)	0.47 (-1.020)	0.13 (2.342)	0.49 (-1.265)	0.40 (-0.323)	0.49 (-1.297)	0.43 (-0.622)	0.44 (-0.762)	0.30 (0.653)
Ambient NOx concentration (ppm)	0.032 (0.488)	0.015 (1.233)	0.029 (-0.853)	0.024 (-0.108)	0.032 (-1.300)	0.032 (-1.300)	0.030 (-1.002)	0.010 (1.979)	0.019 (0.637)	0.015 (1.233)	0.027 (-0.555)	0.021 (0.339)	0.034 (-1.598)	0.026 (-0.406)	0.024 (-0.108)	0.02 (0.488)	0.024 (-0.108)	0.017 (0.935)
Ambient Photochemical oxidant concentration (ppm)	0.030 (0.304)	0.033 (-0.560)	0.030 (0.304)	0.030 (0.304)	0.028 (0.880)	0.028 (0.880)	0.027 (1.168)	0.036 (-1.424)	0.023 (2.320)	0.036 (-1.424)	0.031 (0.016)	0.030 (0.304)	0.031 (0.016)	0.031 (0.016)	0.037 (-1.712)	0.033 (-0.560)	0.031 (0.016)	0.034 (-0.848)
Ambient PM concentration (ppm)	0.013 (2.842)	0.021 (0.806)	0.027 (-0.721)	0.023 (0.297)	0.024 (0.042)	0.025 (-0.212)	0.028 (-0.976)	0.022 (0.551)	0.023 (0.297)	0.022 (0.551)	0.029 (-1.230)	0.020 (1.060)	0.027 (-0.721)	0.026 (-0.467)	0.023 (0.297)	0.028 (-0.976)	0.025 (-0.212)	0.029 (-1.230)

Table 2. The original values of entering variables of the cities of interest.
Note: The number in the parentheses denotes the normalized value of each variable, i.e. the value of the 3rd-level indicator, in a specific category.

Variable \ City	Sapporo	Sendai	Saitama	Chiba	Tokyo (special wards)	Kawasaki	Yokohama	Niigata	Shizuoka	Hamamatsu	Nagoya	Kyoto	Osaka	Sakai	Kobe	Hiroshima	Kitakyushu	Fukuoka
Per capita income (10^4 ¥ (2008 prices)/yr)	345.53 (-0.437)	322.62 (-1.147)	381.64 (0.682)	338.35 (-0.659)	400.48 (1.266)	395.05 (1.098)	437.29 (2.407)	372.08 (0.386)	369.29 (0.300)	361.56 (0.060)	345.32 (-0.443)	353.12 (-0.201)	338.79 (-0.646)	323.91 (-1.107)	361.78 (0.067)	379.98 (0.631)	345.08 (-0.450)	301.29 (-1.808)
The annual rainfall(mm)	843.0 (-2.032)	1,349.0 -0.496)	1,392.5 (-0.364)	1,639.0 (0.384)	1,857.5 (1.047)	1,919.0 (1.233)	1,919.0 (1.233)	1,530.0 (0.053)	1,955.5 (1.344)	1,869.5 (1.083)	1,579.5 (0.203)	1,430.5 (-0.249)	1,262.5 (-0.759)	1,262.5 (-0.759)	1,041.0 (-1.431)	1,148.50 (-1.105)	1,447.0 (-0.199)	1,780.5 (0.813)
The ratio of natural surfaces within the total area (%)	61.55 (0.393)	70.27 (0.785)	50.20 (-0.118)	56.09 (0.147)	17.28 (-1.598)	27.50 (-1.139)	32.60 (-0.909)	76.48 (1.064)	85.41 (1.465)	78.11 (1.137)	30.89 (-0.986)	71.18 (0.825)	13.61 (-1.763)	33.80 (-0.855)	68.97 (0.726)	74.07 (0.956)	50.38 (-0.110)	52.38 (-0.020)
The spatial availability of hospital bed (number/km²)	36.04 (-0.408)	17.46 (-0.850)	39.61 (-0.323)	35.38 (-0.424)	133.95 (1.922)	73.85 (0.492)	66.56 (0.318)	16.07 (-0.883)	6.06 (-1.121)	6.82 (-1.103)	84.18 (0.738)	29.55 (-0.562)	155.47 (2.434)	87.41 (0.814)	35.45 (-0.422)	18.93 (-0.815)	43.16 (-0.239)	71.41 (0.434)
The spatial availability of doctors (number/km²)	50.73 (-0.535)	30.17 (-0.767)	78.63 (-0.219)	69.02 (-0.328)	316.36 (2.472)	140.24 (0.479)	139.33 (0.468)	26.92 (-0.804)	9.51 (-1.001)	11.78 (-0.976)	152.04 (0.612)	46.87 (-0.578)	297.21 (2.255)	117.45 (0.221)	63.37 (-0.392)	30.98 (-0.758)	61.83 (-0.409)	120.88 (0.259)
Crime crack rate (%)	40.99 (0.729)	33.61 (-0.347)	35.00 (-0.144)	36.13 (0.021)	41.95 (0.870)	43.87 (1.150)	45.51 (1.389)	32.57 (-0.499)	36.75 (0.111)	31.38 (-0.673)	27.98 (-1.168)	27.94 (-1.174)	26.53 (-1.380)	22.91 (-1.909)	35.83 (-0.023)	45.24 (1.350)	40.74 (0.693)	42.88 (1.005)
The spatial availability of disaster assistance (case/km²)	62.33 (-0.654)	47.60 (-0.713)	224.25 (0.002)	165.18 (-0.237)	783.25 (2.266)	383.32 (0.646)	334.14 (0.447)	39.94 (-0.744)	18.61 (-0.831)	19.60 (-0.827)	294.39 (0.286)	83.57 (-0.568)	869.85 (2.617)	277.70 (0.218)	114.38 (-0.443)	49.88 (-0.704)	92.74 (-0.531)	166.91 (-0.230)
The spatial intensity of fixed phone and mobile phone services registered (number/km²)	513.06 (-0.583)	432.79 -0.622)	1,508.39 (-0.100)	1,041.03 (-0.327)	8341.10 (3.215)	2,858.91 (0.555)	2,622.62 (0.440)	353.54 (-0.661)	227.08 (-0.722)	181.19 (-0.744)	2,481.46 (0.372)	612.89 (-0.535)	1,955.58 (1.573)	1,405.99 (-0.150)	871.38 (-0.409)	434.04 (-0.622)	559.96 (-0.561)	1,471.64 (-0.118)
The spatial intensity of internet service registered (number/km²)	3,723.07 (-0.763)	2,425.76 (-0.840)	26,359.83 (0.589)	18,244.63 (0.104)	26,962.28 (0.625)	52,788.36 (2.167)	17,421.92 (0.055)	2,260.09 (-0.850)	2,099.09 (-0.860)	1,961.09 (-0.868)	1,9133.48 (0.157)	2,649.58 (-0.827)	35,864.38 (1.156)	53,154.55 (2.189)	8,122.09 (-0.500)	2,588.69 (-0.831)	8,724.48 (-0.464)	12,478.38 (-0.240)
Sewage prevailing rate (%)	99.70 (0.642)	97.60 (0.422)	85.00 (-0.896)	97.10 (0.370)	100.00 (0.673)	99.30 (0.600)	99.80 (0.652)	73.42 (-2.107)	75.7 (-1.868)	74.1 (-2.036)	98.60 (0.527)	99.20 (0.590)	99.90 (0.663)	93.9 (0.035)	98.60 (0.527)	92.90 (-0.069)	99.80 (0.652)	99.50 (0.621)
The recycling ratio of general waste (%)	9.54 (-0.026)	10.17 (0.062)	22.03 (1.688)	20.85 (1.525)	12.28 (0.350)	6.22 (-0.481)	13.24 (0.483)	25.68 (2.187)	6.94 (-0.381)	10.67 (0.130)	0.60 (-1.251)	5.65 (-0.559)	3.07 (-0.912)	3.15 (-0.901)	4.23 (-0.754)	14.77 (0.692)	3.36 (-0.873)	2.59 (-0.979)
The ratio in the municipal expenditure on education (%)	7.91 (-0.938)	11.27 (0.801)	10.76 (0.540)	10.36 (0.330)	13.11 (1.756)	8.07 (-0.860)	8.37 (-0.700)	10.62 (0.466)	9.27 (-0.234)	12.27 (1.321)	8.44 (-0.668)	7.68 (-1.059)	7.43 (-1.190)	9.62 (-0.054)	9.65 (-0.040)	13.81 (2.120)	8.11 (-0.834)	8.27 (-0.755)
The density of college students (number/km²)	45.36 (-0.554)	61.71 (-0.459)	91.91 (-0.284)	95.23 (-0.264)	758.28 (3.588)	212.62 (0.418)	181.74 (0.238)	27.12 (-0.660)	10.35 (-0.757)	7.24 (-0.775)	272.31 (0.764)	159.46 (0.109)	125.84 (-0.086)	79.48 (-0.356)	115.48 (-0.147)	33.01 (-0.626)	44.72 (-0.558)	210.95 (0.408)
The spatial intensity of museums, libraries, natural and cultural heritage appointed (number/km²)	0.074 (-0.491)	0.077 (-0.488)	0.221 (-0.363)	0.107 (-0.463)	4.510 (3.368)	0.277 (-0.314)	0.334 (-0.265)	0.088 (-0.479)	0.055 (-0.508)	0.039 (-0.521)	0.573 (-0.057)	2.578 (1.687)	1.345 (0.615)	0.393 (-0.213)	0.355 (-0.247)	0.064 (-0.500)	0.066 (-0.498)	0.337 (-0.262)

Table 2. The original values of entering variables of the cities of interest. (*conti.*)
Note: The number in the parentheses denotes the normalized value of each variable, i.e. the value of the 3rd-level indicator, in a specific category.

Table 3 shows the points of overall score and the 1st-level indicator of each city. Based on the situation in 2008, Top 3 cities in terms of the global warming adaptation are Sapporo, Hiroshima and Niigata; on the other hand, the last three ones are Fukuoka, Osaka and Nagoya. The overall score and the 1st-level indicators give a comprehensive image of urban system performance. Furthermore, the 2nd-level and the 3rd-level indicators can provide information to make substantial strategy for global warming adaptation on a city level. Table 4 gives the results of the 2nd-level and original indicators for each city.

City	Overall Score	The 1st-level indicator		
		Pressure and State	Function	Coordination
Sapporo	0.452 (1)	0.959 (1)	-0.184 (15)	-0.689 (18)
Sendai	0.196 (4)	0.384 (3)	-0.126 (12)	0.036 (5)
Saitama	-0.129 (6)	-0.277 (15)	0.115 (6)	0.022 (6)
Chiba	0.052 (9)	0.033 (10)	0.135 (5)	-0.086 (8)
Tokyo (special wards)	0.011 (10)	-0.710 (18)	0.528 (1)	2.789 (1)
Kawasaki	0.112 (7)	0.105 (7)	0.266 (3)	-0.313 (14)
Yokohama	0.181 (5)	0.182 (6)	0.336 (2)	-0.288 (13)
Niigata	0.294 (3)	0.471 (2)	0.089 (7)	-0.155 (10)
Shizuoka	-0.073 (14)	-0.067 (14)	0.048 (8)	-0.473 (16)
Hamamatsu	-0.019 (11)	-0.013 (11)	-0.083 (11)	0.139 (3)
Nagoya	-0.732 (18)	-1.055 (17)	-0.312 (17)	-0.055 (7)
Kyoto	-0.033 (12)	-0.050 (12)	-0.048 (9)	0.115 (4)
Osaka	-0.465 (17)	-0.651 (16)	-0.141 (13)	-0.318 (15)
Sakai	-0.068 (13)	0.078 (9)	-0.319 (18)	-0.192 (11)
Kobe	0.093 (8)	0.203 (5)	-0.052 (10)	-0.134 (9)
Hiroshima	0.315 (2)	0.371 (4)	0.137 (4)	0.510 (2)
Kitakyushu	-0.079 (15)	0.094 (8)	-0.236 (16)	-0.651 (17)
Fukuoka	-0.107 (16)	-0.059 (13)	-0.152 (14)	-0.258 (12)

Table 3. The overall score and the 1st-level indicators of the interested city.
Note: The number in the parentheses denotes the rank of each indicator in a specific category.

Indicator / City	Pressure and State				Function					Coordination
	Population Scale	Environmental Pressure	Catastrophe Pressure	Environmental Quality	Production Capacity	Natural Supporting System	Public Supporting System	Information Exchange Intensity	Metabolism Capacity	Civilization Development Potential
Sapporo	0.352(6)	0.576 (1)	1.223 (1)	1.199 (1)	-0.437 (11)	-0.092 (10)	-0.235 (12)	-0.673 (12)	0.308 (6)	-0.689 (18)
Sendai	0.848 (1)	0.322 (4)	0.239 (7)	0.488 (4)	-1.147 (17)	0.529 (6)	-0.658 (14)	-0.731 (15)	0.242 (7)	0.036 (5)
Saitama	0.159 (9)	0.274 (6)	-0.586 (16)	-0.419 (15)	0.682 (4)	-0.167 (12)	-0.150 (8)	0.244 (7)	0.396 (4)	0.022 (6)
Chiba	0.407 (5)	-0.406 (15)	0.058 (10)	0.163 (6)	-0.659 (15)	0.194 (8)	-0.228 (11)	-0.111 (8)	0.948 (1)	-0.086 (8)
Tokyo (Special Wards)	-1.775 (18)	-0.407 (16)	-0.688 (17)	-0.124 (9)	1.266 (2)	-1.069 (17)	1.927 (1)	1.920 (1)	0.512 (3)	2.789 (1)
Kawasaki	-0.237 (14)	-0.035 (13)	0.358 (6)	-0.208 (10)	1.098 (3)	-0.664 (14)	0.699 (3)	1.361 (3)	0.060 (8)	-0.313 (14)
Yokohama	-0.414 (16)	0.332 (3)	0.436 (4)	-0.267 (11)	2.407 (1)	-0.481 (13)	0.670 (4)	0.248 (6)	0.567 (2)	-0.288 (13)
Niigata	0.307 (7)	-0.304 (14)	0.863 (2)	0.365 (5)	0.386 (6)	0.862 (3)	-0.722 (16)	-0.755 (16)	0.040 (9)	-0.155 (10)
Shizuoka	0.245 (8)	-0.006 (12)	-0.528 (15)	1.074 (2)	0.300 (7)	1.441 (1)	-0.690 (15)	-0.791 (17)	-1.125 (18)	-0.473 (16)
Hamamatsu	0.648 (3)	0.231 (8)	-0.349 (13)	0.119 (7)	0.060 (8)	1.126 (2)	-0.875 (18)	-0.806 (18)	-0.953 (17)	0.139 (3)
Nagoya	-0.383 (15)	-0.746 (17)	-1.522 (18)	-0.584 (17)	-0.443 (12)	-0.748 (15)	0.088 (6)	0.265 (5)	-0.362 (16)	-0.055 (7)
Kyoto	0.146 (10)	0.360 (2)	-0.456 (14)	0.562 (3)	-0.201 (10)	0.611 (4)	-0.722 (16)	-0.681 (13)	0.015 (10)	0.115 (4)
Osaka	-1.560 (17)	-0.923 (18)	-0.236 (12)	-0.760 (18)	-0.646 (14)	-1.562 (18)	1.482 (2)	1.364 (2)	-0.125 (13)	-0.318 (15)
Sakai	-0.120 (13)	0.135 (9)	0.223 (8)	-0.283 (12)	-1.107 (16)	-0.836 (16)	-0.223 (9)	1.019 (4)	-0.433 (15)	-0.192 (11)
Kobe	0.066 (11)	0.258 (7)	0.434 (5)	-0.503 (16)	0.067 (9)	0.295 (7)	-0.319 (13)	-0.455 (10)	-0.113 (12)	-0.134 (9)
Hiroshima	0.811 (2)	0.318 (5)	0.476 (3)	-0.346 (13)	0.631 (5)	0.544 (5)	-0.223 (9)	-0.726 (14)	0.311 (5)	0.510 (2)
Kitakyushu	0.054 (12)	0.024 (10)	0.193 (9)	-0.100 (8)	-0.450 (13)	-0.128 (11)	-0.145 (7)	-0.512 (11)	-0.110 (11)	-0.651 (17)
Fukuoka	0.445 (4)	-0.003 (11)	-0.137 (11)	-0.377 (14)	-1.808 (18)	0.147 (9)	0.325 (5)	-0.179 (9)	-0.179 (14)	-0.258 (12)

Table 4. The 2nd-level indicators of the interested cities.
Note: The number in the parentheses is the rank of each 2nd-level indicator in a specific category.

From Table 2-4 the comparative advantages and disadvantages of each city in 2008, in terms of global warming adaptation and human security, could be observed under the assumed intrinsic relationships of the precautionary indicator system. The upper-level cities in the overall ranking primarily obtain high scores on "Pressure and State" while this perspective is highlighted for the precautionary purpose in this study. Even the top 1 city, Sapporo, has low rankings in the other two 1st-level indicators, the differences compared with other cities are not too large. This is also one reason that the cities with high 1st-level scores would occupy high rankings. Still, some important policy implications for the development of adaptation strategies could be found by examining the scoring structure in Table 2-4. In principle, some implications could be observed as the following:

Pressure and State

Sapporo, Niigata and Sendai obtain the highest scores in this category, implying that the current pressures on global warming and human security are less than other cities in 2008. Regarding global warming, cities in north areas, e.g., Sapporo, Sandai and Niigata, might face less threatens of heat waves and the extreme weather than the sourth cities. Such outcome implies the geological condition would be an influencing factor on the regional climate stability. In view of the catastrophe pressures and climate change adaptation, meteorologically, the adequate latitude condition of a city might shift to a higher level than that of most current major cities in Japan. However, variables related to some sorts of natural hazards, e.g., earthquakes and tsunami, are not included herein while it is difficult to obtain appropriate quantitative precautionary variables in the existing statistics. On the other hand, Nagoya, Tokyo (special wards) and Osaka get relatively low scores while the current megacity scale is not suitable to relieve the pressures on global warming and human security.

Regarding the "Population Scale" indicator, for lower-scoring cities, the control of high population and household densities could be considered, while the later term seems to be a characteristic of modern society (Weng et al., 2009). As for the "Environmental Pressure" indicator, countermeasures on eliminating the resources and energy consumption and controlling the heat island effect could be taken into consideration. Also, incentives for using public transportation could be further designed. In fact, the public environmental education should be promoted as well so as to change the unsustainable lifestyle. In terms of the estimates of the "Catastrophe Pressure" and "Environmental Quality" indicators, as mentioned earlier, the urban heat island effect should be noticed and controlled by increasing green area inside the city while this argument is also highlighted in the "Natural Supporting System" indicator. In addition, the promotion of the green roof at buildings could be a multi-functional measure on pollution mitigation, stormwater runoff control, energy saving and heat island effect mitigation (Cartera & Keeler, 2008). Meanwhile, the restriction of private cars, incentives for using public transportation and the effective management on the pollution sources would reduce the air pollutant emissions associated with global warming and improve the urban environmental quality. In particular, the spatial car density data shows a strong positive relation to the ambient NOx concentration (the correlation coefficient is 0.84 for the original series). Economic instruments, e.g., car taxes and pollutant emission credits, would be potentially effective policy measures. Some strict emission standards of greenhouse gas could be suggested as well. Regarding the human security in urban area, municipal governors should eliminate the occurrence of crime and fire acccidents by launching strict regulations and frequent inspections.

Function

In fact, except for the "Natural Supporting System" indicator, the cities with high population density may have sufficient financial supports to enhance the capacities on this part. Therefore, Tokyo (special wards), Yokohama and Kawasaki have high scores on the "Function" indicator. On the other hand, Kitakyushu, Nagoya and Sakai obtain relatively low scores, implying that the natural service and the public governances should be promoted to cope with essential tasks of adapting global warming and improving human security.

In terms of the "Production Capacity," this study chooses per capita income only as a reference index. Some additional influencing factors might exist in this category, e.g., the technology innovation towards global warming mitigation. However, some quantitative variables might be difficult to be obtained. In addition, since the main purpose of this study is to developing the precautionary indicator for global warming, the weight of this category is not significant. In this sense, a moderate representative index might be sufficient. However, the representativeness of this index might be biased sine many employees are not inhabitants in the area where they work. As for the "Natural Supporting System" indicator, mainly, an open natural space inside the city is expected to enhance the potential of the service of natural systems. In addition, there is high potential to implement a variety of ecological engineering approaches in urban area to increase the natural supporting capacity (Chapman & Blockley, 2009). In addition, as aforementioned in the interpretation of the "Pressure and State" indicator, constructing new urban parks and green roof (or roof gardening) are effective measures. Regarding the "Public Supporting System" indicator, concerning about the human security capacity, the development of the public health service and the social security enhancement should be improved although the tasks might be low priority in conventional urban governances. In order to distribute in-time emergent alarms and implement reaction plans, the enhancement of the information change systems is required. In addition, the practice of the emergency reaction plans should be performed routinely. Though not strongly related, the metabolism capacity in large cities should be promoted considering the improvement of all the perspectives of urban sustainability.

Coordination

In this category, Tokyo (special wards), Hiroshima and Kobe have high scores while Shizuoka, Kitakyushu and Sapporo get relatively low scores on the "Civilization Development Potential" indicator. Examining the detailed scoring structure in Table 1, the low ratio of the public expenditure on education seems to be a main reason for this result. Meanwhile, more public education facilities are expected in the low-score cities to provide more opportunities for adult education. The public education facilities indeed could serve as platforms for promoting the education for sustainable development (ESD), which highlights issues covering global warming mitigation and human security improvement (UNESCO, 2011). Still, some additional indicators are required to take the sustainable industrial structure into consideration in this part.

Although the evaluation outcomes come out only by using the data in 2008, the results are informative for the decision-makers and citizens. The related stakeholders could find potential directions to improve upon the current situation in the comparative analysis. Based on the previous observations, concrete adaptation strategies of global warming mitigation and human security improvement for each city are proposed in Table 5.

City	Proposal	
Sapporo	Pressure and State	Improve the greening of roads
	Function	Build water storage facilities and facilitate the water resources management against potential droughts; Improve the spatial homogeneity of the resources of public health;
	Coordination	Improve the public investment on education; Improve the regional research capacity
Sendai	Pressure and State	Improve the greening of roads and promote the utilization of public transportation systems
	Function	Increase the resource (doctors and facilities) of public health care; Improve the capacity of crime crack by increasing the manpower; Establish efficient alarm networks for natural hazards and human security
	Coordination	Improve the regional research capacity; Improve the resources and infrastructures of public education
Saitama	Pressure and State	Manage the utilization of car by imposing a higher car tax for instance; Promote roof gardening, improve the drainage systems, and establish detention ponds to prevent from potential stormwater; Create natural surfaces to eliminate potential heat waves, by roof gardening for example
	Function	Increase the natural surfaces and promote green roof or green buildings by revising built environment regulations; Create urban parks; Increase the resource of public health care; Improve the capacity of crime crack and hazard security, by increasing the manpower for instance
	Coordination	Improve the regional research capacity; Improve the resources and infrastructures of public education
Chiba	Pressure and State	Encourage energy/natural gas saving by using economic incentives and adjusting the prices for instance
	Function	Improve the regional research capacity
	Coordination	Improve the regional research capacity; Improve the resources and infrastructures of public education

Table 5. Proposals towards sustainable city for interested cities.

City	Proposal	
Tokyo (special wards)	Pressure and State	Control the population/household density; Encourage water/natural gas saving by using economic incentives and adjusting the price levels for instance; Promote roof gardening, improve the drainage systems, and establish detention ponds to prevent from potential stormwater; Control NOx pollution: implement more strict pollution countermeasures such as making more strict emission standards and eliminating pollutant emission sources.
	Function	Increase the natural surfaces and promote green roof or green buildings by revising built environment regulations; Create urban parks;
	Coordination	Under stable development
Yokohama	Pressure and State	Manage the utilization of car by imposing a higher car tax for instance
	Function	Increase the natural surfaces and promote green roof or green buildings by revising built environment regulations; Create urban parks
	Coordination	At an appropriate level
Niigata	Pressure and State	Improve the greening of roads and promote the utilization of public transportation systems; Encourage the water saving by using economic incentives and adjusting the price levels for instance; Improve the greening of roads
	Function	Establish efficient alarm networks for natural hazards and human security
	Coordination	At an appropriate level;
Shizuoka	Pressure and State	Encourage the increase of newborn babies; Promote roof gardening, improve the drainage systems, and establish detention ponds to prevent from potential stormwater
	Function	Increase the resource (doctors and facilities) of public health care; Improve the capacity of hazard security by increasing the manpower; Improve the prevailing of sewage services; Establish efficient alarm networks for natural hazards and human security
	Coordination	Improve the regional research capacity; Improve the resources and infrastructures of public education

Table 5. Proposals towards sustainable city for interested cities. (*conti.*)

City	Proposal	
Hamamatsu	Pressure and State	Improve the greening of roads and promote the utilization of public transportation systems; Prevent from Oxidant pollution: survey the possible precursors' emission and eliminate the sources.
	Function	Increase the resource (doctors and facilities) of public health care; Improve the capacity of crime crack and hazard security, by increasing the manpower for instance; Improve the capacity of hazard security by increasing the manpower; Improve the prevailing of sewage services; Establish efficient alarm networks for natural hazards and human security
	Coordination	Improve the regional research capacity; Improve the resources and infrastructures of public education
Nagoya	Pressure and State	Encourage energy saving by using economic incentives and adjusting the price levels for instance; Manage the utilization of car, e.g. by imposing a higher car tax; Create natural surfaces to eliminate potential heat waves, by roof gardening for example; Prevent crime and fire accidents
	Function	Increase the natural surfaces and promote green roof or green buildings by revising built environment regulations; Create urban parks; Improve the capacity of crime crack and hazard security, by increasing the manpower for instance; Improve the recycling and reuse of general waste (the original data might be questionable due to the natural hazard occurred in the year)
	Coordination	At an appropriate level
Kyoto	Pressure and State	Encourage the increase of newborn babies; Promote roof gardening, improve the drainage systems, and establish detention ponds to prevent from potential stormwater; Create natural surfaces to eliminate potential heat waves, by roof gardening for example
	Function	Improve the capacity of crime crack and hazard security, by increasing the manpower for instance; Establish efficient alarm networks for natural hazards and human security
	Coordination	Improve the public investment on education

Table 5. Proposals towards sustainable city for interested cities. (*conti*.)

City	Proposal	
Osaka	Pressure and State	Control the population/household density; Encourage water/natural gas saving by using economic incentives and adjusting the price levels for instance; Promote the reduction of general waste generation; Manage the utilization of car, e.g. by imposing a higher car tax; Prevent crime; Control NOx pollution: implement more strict pollution countermeasures such as making more strict emission standards and eliminating pollutant emission sources.
	Function	Increase the natural surfaces and promote green roof or green buildings by revising built environment regulations; Create urban parks; Improve the capacity of crime crack and hazard security, by increasing the manpower for instance; Improve the recycling and reuse of general waste
	Coordination	Improve the public investment on education
Sakai	Pressure and State	Encourage natural gas saving by using economic incentives and adjusting the price levels for instance; Manage the utilization of car, e.g. by imposing a higher car tax
	Function	Improve the capacity of crime crack and hazard security, by increasing the manpower for instance; Improve the recycling and reuse of general waste
	Coordination	At an appropriate level
Kobe	Pressure and State	Prevent crime and fire accidents; Prevent from Oxidant pollution: survey the possible precursors' emission and eliminate the sources.
	Function	Improve the recycling and reuse of general waste
	Coordination	At an appropriate level
Hiroshima	Pressure and State	Create natural surfaces to eliminate potential heat waves, by roof gardening for example
	Function	Increase the resource (doctors and facilities) of public health care; Establish efficient alarm networks for natural hazards and human security
	Coordination	At an appropriate level
Kitakyushu	Pressure and State	Encourage the increase of newborn babies; Improve the greening of roads and promote the utilization of public transportation systems
	Function	At an appropriate level
	Coordination	At an appropriate level
Fukuoka	Pressure and State	Create natural surfaces to eliminate potential heat waves, by roof gardening for example
	Function	Improve the recycling and reuse of general waste
	Coordination	At an appropriate level

Table 5. Proposals towards sustainable city for interested cities. (*conti.*)

In addition, applying the ideas of the EKC, a quadratic equation is preliminarily established to fit the possible relationship between the overall scores and the area of the regions. The ordinary least squares (OLS) method is used to estimate the parameters, and the results are statistically diagnosed to confirm the statistic credibility of the model. As shown in Fig.3, the results of the F test and the t test denote that most of the parameter estimators are significant; the Durbin-Watson (DW) statistic shows that no significant serial correlation problem exist in the error term. However, only about 17% of the model variances are explained by the current one; one reason is that the equation only considers the influencing factor of area, on the basis of the concept of EKC. Still, the developed equation could provide a preliminary estimation for the optimal area of a sustainable city for the research purpose. In Fig. 3, the results imply that 987.26 km^2 would be the optimal area according to the methodological assumptions and data in 2008. Besides, the area of the top 2 cities in the ranking is close to this optimal value, supporting the current outcome. On the other hand, satisfactory results are not obtained in developing the function of the overall scores and the population scales of the interested regions. Given that more rational weights of the indicators, the result suggests that the coupling of the indicator system and the EKC could be an informative tool to analyse the optimal development scale from a variety of perspectives with the current available statistics, and thus this methodology could aid future urban design towards sustainable development.

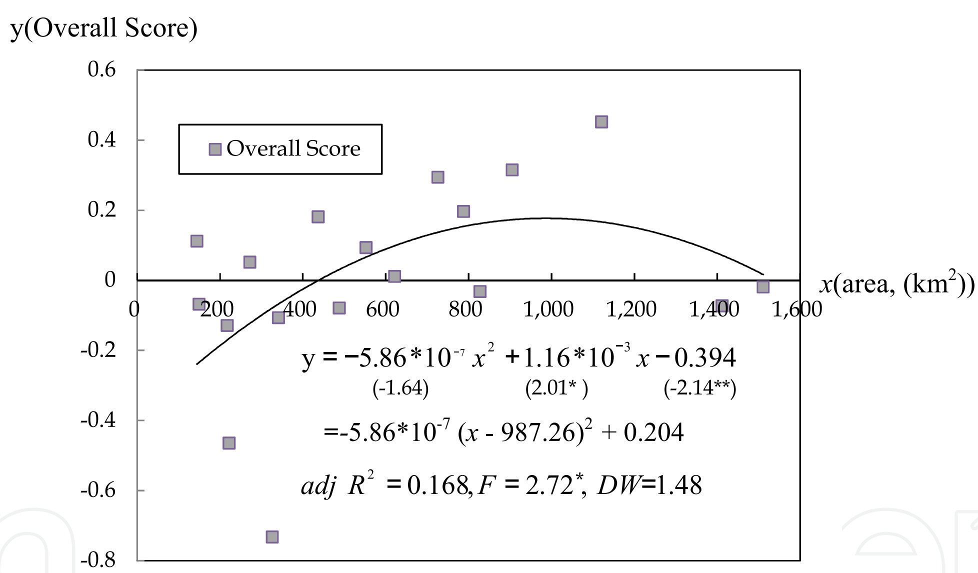

Fig. 3. The relationship between the overall scores and areas for the study regions. Note: Values in the parentheses are t statistics for the parameter estimator; * and ** denote significance at the 10% and 5% levels, respectively.

In fact, some deficiencies in this study are expected to be improved at the next step. First, an additional analysis on the weights in the current precautionary indicator system is required. Second, the aggregation process in the precautionary indicator system actually assumes that the intrinsic relationships among the variables are linearly. In this sense, the weights of the indicators serve as the coefficients in a linear equation in each category. Therefore, the potential collinearity among the indicators in the current indicator system has to be further examined given that a more credible spatial-temporal panel data. Third, regarding the cooperation and competition among the cities, some neighboring cities may have strong interactions to form a regional economy. For example, in the eastern Japan, several major cities comprise of the informal Kando regional economy. In this sense, the current methodology of the development of indicator systems should take the interactions among stakeholders into consideration by adopting import/export flows. Still, the current methodology could provide adaptation strategies to a certain extent with a small data requirement.

4. Conclusion and future prospect

Considering the composite socio-economic-environmental relationships, this study makes an attempt to develop a precautionary indicator system to quantify the degree of the risks with regard to global warming and human security in urban areas. An normalization procedure considering the attributs of impacts is proposed to develop the indicator system. Regarding the improvement of the current methodology, two parts could be further studied. Firstly, considering the manipulability of the calculation, the behaviors of the variables are assumed to obey the standard normal distribution in this study while some might not. Further distribution tests could be implemented for the recognition of the behaviour of each index. Secondly, the weights within the hierarchies could be re-structured by using the AHP or ANP-like methods, e.g., AHP, fuzzy-AHP, or ANP methods, so that all the stakeholders' view points could be taken into consideration.

Using the official data in 2008, the preliminary empirical results provide concrete adaptation strategies for the major cities in Japan. Furthermore, every city could find some solutions to improve their capacity regarding the global warming and human security. In addition, concerning the catastrophe pressures and the climate change adaptation, the adequate latitude condition of a city might shift to a higher level than that of most major cities in Japan. Furthermore, using the overall scores of the precautionary indicator systems, a preliminary EKC is established to discover the optimal size of a city, showing that a city in the area of around 987.26 km^2 would be adequate for the purpose of global warming adaptation and human security improvement with regard to city governances. Consequently, as shown in the demonstrated EMC example, more attributes on the city scales could be exploited based on the established indicator sytem using a comprehensive data. Based on the outcomes of this study, the precautionary indicator system and the proposed adaptation strategies regarding the global warming mitigation and human security improvement would contribute to the facilitation of the current urban planning for sustainable development.

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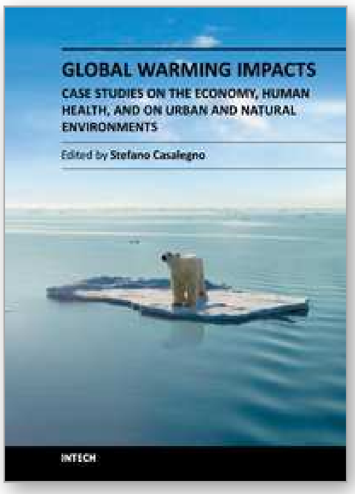

Global Warming Impacts - Case Studies on the Economy, Human Health, and on Urban and Natural Environments
Edited by Dr. Stefano Casalegno

ISBN 978-953-307-785-7
Hard cover, 290 pages
Publisher InTech
Published online 03, October, 2011
Published in print edition October, 2011

This book addresses the theme of the impacts of global warming on different specific fields, ranging from the regional and global economy, to agriculture, human health, urban areas, land vegetation, marine areas and mangroves. Despite the volume of scientific work that has been undertaken in relation to each of each of these issues, the study of the impacts of global warming upon them is a relatively recent and unexplored topic. The chapters of this book offer a broad overview of potential applications of global warming science. As this science continues to evolve, confirm and reject study hypotheses, it is hoped that this book will stimulate further developments in relation to the impacts of changes in the global climate.

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