Application of System Dynamics Model for Energy Policy Analysis at Local Governmental Level: a Review and Case Study

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System dynamics (SD) has been used for policy analysis and strategic planning in such fields as environment and energy both nationally and internationally. However, few applications of SD have been demonstrated for the local level policy analysis. In this paper, we discuss the effectiveness of the SD application to energy policy at local level. We first review 12 papers that dealt with energy planning and environmental policies at national and local governmental level and summarize them in terms of study objectives, main variables used for modeling, evaluated indicators and spatiotemporal boundaries represented in the model. We then conduct a case study for Suita City in Osaka prefecture by applying the SD method, with an aim to examine the appropriateness of Suita's future energy planning and vision set in 2020. This study looks into two scenarios; a) the Suita's energy plan scenario (the SEP scenario), and b) the business as usual scenario (the BAU scenario) and compares the two scenarios in terms of Carbon dioxide (CO_2) emissions and costs.

Our preliminary results show that if Suita City follows the BAU scenario, CO_2 emissions by 2020 will become 1.55-fold of those in 1990. In the SEP scenario, which aims to promote an installation of renewable energy of solar photovoltaic system from 2011 to 2020, the total energy saving reaches 356.9 Terajoule and the total reduction of CO_2 emissions reaches 97809.7 tons if we compare to BAU scenario. Although our calibration shows Suita should spend over 87.4 billion Yen in the SEP scenario, the policy cost is just around 894.48 Yen per one ton of CO_2 emissions reduction, which is much lower than the reduction costs estimated by Intergovernmental Panel on Climate Change through the carbon emissions reduction from power generations.

Key Words : *system dynamics,residential energy sector,solar photovoltaic promotion, Suita City*

1. INTRODUCTION

A momentous event in 1997 at Kyoto Japan elicited an international agreement which sets binding targets for industrialized countries and the European community for reducing Greenhouse gas (GHG) emissions[1)]. Accordingly, Japan has also been making efforts to set its own targets at governmental as well as local levels[2)]. Suita City, located in the northern part of Osaka Prefecture in Japan, also intend to pursue a low-carbon society in the city. As of 2011, Suita has 353,881 residents with about 157,500 households, making it the seventh largest city in Osaka Prefecture. The city broadly outlines its measures to achieve the goal of pursuing a low-carbon society by means of reviewing the behavior of citizens and business sectors, installation of new energy and energy-saving equipment, introduction of positive energy type line equipment, and human resource development through environmental education[3]. The historical trend of energy consumption and Carbon dioxide (CO_2) emissions in Suita demonstrates that energy consumptions in business and residential sectors have increased over time along with an increasing of CO_2 emissions in the sectors[3] (**Fig.1**). Assuming that technologies to reduce CO_2 emission in the industrial and transportation sectors have appropriately improved to some extent with measures taken, it is suggested that the government of Suita pay more attention to business and residential sectors for reaching Suita's policy target for a low-carbon society . We argue that scientific approach is needed for policy analysis of renewable energy promotion, which, among others, is the key to achieve a low-carbon society.

In this study we aim to develop a system dynamics (SD) energy model for policy analysis of the renewable energy promotion of Solar photovoltaic (Solar PV) and its potential reduction of CO_2 emissions with a case study of residential sector in Suita. We first conduct a literature review about SD applications to policy analysis particularly at the national and local governmental level. We selected 12 papers related to environmental policies and energy planning and summarized them in terms of several dimensions, such as, main variables used for modeling. We then carry out a preliminary case study for Suita by applying the SD method with an aim to examine the appropriateness of Suita's future energy planning and vision set in 2020.

2. LITERATURE REVIEW

In this section, we review 12 papers of the application in energy system and environmental field. We then summarized essential concepts based on the review for the city level applications.

(1) System Dynamics Action in Energy System

In the early 70's depletion of energy resources was the major concerens. In 1972, Naillin the U.S Department of Energy developed a simulation model based on life cycle theory of oil and gas and discovery analyzed national level policies to reduce the US

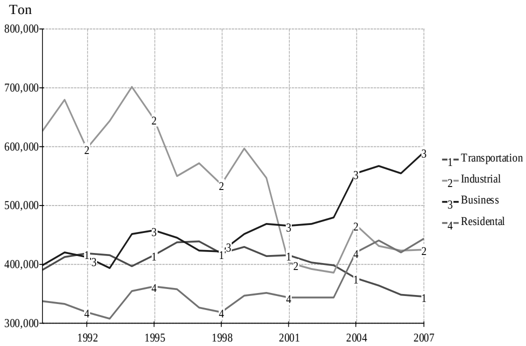

Fig.1 The historical trend of CO_2 emissions for each sector.

dependency on foreign oil[4]. However, Sterman[5] integrated an energy system into macroeconomy and examined the dynamic interactions between energy depletion rising energy costs, economic growth, inflation, interest rate, and living standards. Sterman was followed by a series of research that analyzed the macroeconomic effects of the energy transition and the effects of government subsidies for energy technologies. For example, Ford[6] applied the system dynamics approach to study the power industry systemsin the US. He demonstrated the "death spiral" theory in the industry system, which considers the interactions among the need for capacity expansion to serve the growing demand, the industry that faces the financial challenge for the expansion, the regulators who normally allow the industry generate the allowed revenues and the consumers' reaction to the electric rates/price. Another study using SD approach was conducted by Longbin and Moxnes[7]. Their model on study of Chinese steel industry focused mainly on energy efficiency technology development (through 4 policies) and substitution among the production process of steel. They revealed that the energy tax recycled as research and development subsidy (energy tax converting into subsidy) was the most effective policy instrument.

A number of study demonstrated SD application on energy system at the regional level also. Dyner et al.[8] presented a methodology to support integrated energy policy making for urban residential sector, which aims to replace traditional households electricity appliances with more efficient alternatives, to see the effects on energy efficiency. In addition, Ford[9] used SD approach to demonstrate how boom and bust might appear in the electric system under the crisis condition such a case as in California (U.S) in 2000 and 2001. He included new generating capacity as an endogenous input, which had been considered as an exogenous input in previous studies. In addition, the model employed the user interface design (SD

Table 1 A brief summary of some literature studies for several dimensions.

Literature	Objective of study	Variables	Evaluation Indicators	Spatiotemporal Boundary
Sterman[5)]	To aid in designing a framework for energy policy analysis that focuses on the underlying structural causes of the macroeconomic effects of energy policies over the long term	GDP ; Consumption ; Investment savings ; Energy production ; Energy demand ; Population ; Technological change ; Tax Rates ; Energy Policies ;etc	The real price of energy ; the fraction of economic output devoted to energy production ; reductions in economic growth due to energy ; etc.	Place: U.S. (national level) Horizon time: 100 years (1950-2050)
Longbin, Z. and Moxnes, E.[7)]	To explore the internal mechanism of the Chinese steel industry and to see how energy conservation policies help to reduce the high energy demand and energy expenditure during the economy transition period	steel demand ; Average energydemand ; energycost ; CO_2 emissions ; R&D investment ; GDP ; Population ; Otherproduction costs ; Open hearth furnace (OHF) proportion ; Reference energy price ; Reference percentage investment in R&D ; etc.	Energy demand ; CO_2 emissions ; Energy expense	Place: China (national level) Horizon time: 120 years (1980-2100)
Dyner et al.[8)]	To present a methodology to support integrated energy policy making in the case of a strategy to substitute traditional households electricity appliances with more efficient alternatives	Population ; Average income ; Electricity consumption ; Electricity generation capasity ; Energy alternatives ; Financial Electricity constraints ; Investment incentives ; etc.	Annual Equivalent Cost	Place: Medellin city (Colombia) Horizon time: 20 years
Ford[9)]	To demonstrate how boom and bust might appear in the electricity system using computer simulations	Combined Cycle (CC) generation under construction and on line ; hourly operation; expected levelized cost of anew CC generation ; energy demand ; electricity supply reserve margins ; Average market price : gas price ; etc	Electricity market price	Place: California (USA) Horizontime:11 years (1998-2009)
Vauedreuil, et al.[10)]	To develop a system dynamics computer simulation model to forecast the energy demands for the Montachusett region under a variety of simulations and scenarios	'Population ; Labor force; Housing ; Land use ; Commercial businesses ; Industrial Businesses ; Region attractiveness ; Total energy demand ; etc	Energy use per capita	Place: The Montachu-settregion(U.S.) Horizon time: 100 years(1970-2070)
Trappey et al.[11)]	To develop a formal cost–benefit analysis methodology, considering both qualitative and quantitative factors, to evaluate the feasibility of renewable (e.g., solar) energy policies	Population ; Carbon reduction gap ; Planning the installation capacity of PV systems and solar water heaters; electricity saved by solar energy and PV system ; The carbon reduction from wind power etc.	CO_2emisions ; the cost of policyimplementation	Place: Penghu Islands (Taiwan) Horizon time: 50 years (1990-2040)

management flight simulators) for highly interactive use to promote general learning through interactive experimentation. Furthermore, Vauedreuil et al.[10)] to forecast the energy demands for the Montachusett region in the U.S. under nine different scenarios. They chose the cumulative energy per capita as indicator to compare the nine scenarios. This study is characterized by a participatory modeling, which conducted workshops, questionnaire survey and report meeting to obtain public input and involvement during the modeling process. Another study by Trappey et al.[11)] attempted to determine which renewable energy policies are suitable for Penghu Island in Taiwan to achieve a stable carbon emissions balance. Using the SD approach, they demonstrated a more comprehensive cost-benefit analysis to evaluate the feasibility of renewable energy policies.

(2) System Dynamics Action in Environmental system

The SD approach has been widely used in environmental field as well. For example the development of a policy model for understanding and managing the water flows in the Mono Basin of northern California, the growth and collapse of the deer herd on the Kaibab Plateau in northern Arizona, the long-term effects of the flow of dichlorodiphenyltrichloroethane (DDT) pesticides through the soil, air, and ocean and into the bodies of fish, and so forth[12]. The Mono Basin is an important source of water supply for Los Angeles, but the lake ecological conditions were gradually degraded. Ford[13] developed an SD model of Mono Basin to project the future size of the lakeand the amount water exported to Los Angeles under different policies. In transportation sector, Han and Hayashi[14] developed an SD model for policy assessment and CO_2 mitigation potential analysis with a case study of the inter-city passenger transport in China. This study incorporated stepwise regression estimation into the model to assess the role of possible determinants of modal share in inter-city passenger transport. The focus of the study is to determine which policy is the most effective to reduce fuel consumption and to mitigate CO_2 emissions in inter-city passenger transport. Sufian and Bala[15] developed an SD model of urban solid waste management (UWSM) for Dhaka city,Bangladesh. The model provides a theoretical framework, 1) topredict solid waste generation and electrical energy recovery from the solid waste, 2) to examine urban solid waste generation and its existing management system, 3) to assess electrical energy generation potentials to meet the electrical energy consumption in the city, and 4) to assess different policy options for the UWSM. Sandkeret al.[16] utilized an SD approach to simulate landscape dynamics in order to understand the trade-offs between conservation and development in case study of Malinau district, a conservation district in Indonesia. They emphasized that their model is designed not for a predicton, but for scoping and exploring complex systems. The primary use of the model is to stimulate discussion and to promote dialog among different stakeholders (conservationists, development actors, and district authorities) who have different perspectives on the trade-off.

Table 1 summarizes some literatures above in terms of study objectives, main variables used for modeling, evaluated indicators and spatiotemporal boundaries represented in the model .

(3) System Dynamics Approach Learning

Literature studies have shown that SD approach is an appropriate methodology for policy analysis and strategic planning for both the national and local governmental level . Since the SD deals with combination ideas from different fields and system interactions that are complex and changes over time. Ford[6] believed that the SD approach enabled us to make a useful and unique contribution to our field as long as we are able to see the feedbacks that work in the system being studied, this is the important and unique features of the SD approach.

In this present study, we developed the model by adopting the key concepts and the variables that referred to the literatures. For example considering the socio-economic factors for the endogenous or exogenous variables, to include new generating capacity as an endogenous input for the key concepts, employing the SD management flight simulators for policy experimentation, and so forth. The detail of key concepts and variables that is used in this study can be found in the model conceptualization and formulation section.

3. MODEL CONSTRUCTION

(1) Model Conceptualization and Formulation

In this section we carry out a case study of Suita City. This study develops a system dynamics model to examine two scenarios of the business as usual scenario (the BAU scenario) and the Suita's energy plan scenario (the SEP scenario). The BAU scenario assumes the absence of renewable energy promotion policy, while the SEP scenario assumes the implementation of Solar PV promotion policy starting from last year, 2011. Under the SEP scenario, Suita aims to realize a low-carbon society in which both the CO_2 emissions and dependence on fossil fuel and nuclear energies are reduced. In particular, Suita provides a subsidy for the installation of solar PV system to promote renewable energy application. Lower installation costs by subsidy would increase motivation of households to install solar PV systems on their house. The two scenarios are based on extrapolation of the current reference trend inferred by historical data. In order to see the effectiveness and efficiency of the policy, we compared the two scenarios based on the simulation results in terms of CO_2 emissions and costs. **Table 2** is a summary of the model scenarios.

This study constructs a residential energy SD model for Suita, taking into account the installation of solar PV systems and the government subsidy to promote the installation which are linked to the socio-economic drivers. In the SD model, the transfor-

Table 2 Model scenarios summary.

Component	Scenarios	
	BAU	SEP
Definition	An assumption in the absence of solar PV promotion policy	An assumption the implementation of Solar PV promotion policy
Driving Force		
Policy driver	No subsidy	A subsidy for the installation of solar PV
Socio- economic driver	Population ; GDP per capita ; number person per households ;	
Assumption		
Impact of policy	the continuation of the current trend	A subsidy would increase motivation of households to install solar PV systems on their house
Evaluation Indicator	CO_2 emissions Policy Costs	
Time		
Horizon time	2000 - 2020 (20 years)	
Base time	2000 for GDP per capita ; 2007 for BAU carbon intensity ; 2011 for SEP carbon intensity	
Policy Time	-	2011 - 2020
Parameter Inputs	same	

mation of the descriptive scenarios into a mathematical model is depicted into stock, flow, auxiliaryand information link diagrams. **Fig.2** shows the SD model of this study for both BAU and SEP scenarios. The interrelationship or feedback structures and underlying theories and assumptions used in our model are as follows.

- *Population*: Population in the Suita City.The input value of population is based on the Suita government's own projection[17] and statisticalreports/actual data[18]. (See item 1 in **Table 3.**)
- *Households numbers*: This variable is estimated by using the variables of population and number person per households. We consider the trends in modeling that the number person per households is decreasing whereas the number of households is increasing in Suita[3]. (See items 1and 2 in **Table 3.**)
- *GDP per capita*: we used GDP per capita to measure the income per households. Since Suita City's GDP per capita is unavailable, we use Japan's GDP per capita.The input values of GDP sub-model were derived from World Bank's statistical data[19]. (See items 4 and 5 in **Table 3** and items 1 and 2 in **Table 4)**
- *Income effect on energy consumption*: Households income will affect energy consumption. This variable is formulated using table fuction or an elasticity graph based on historical data[3], whicht measures how the changing of households income affects the energy consumption. (See item 6 in **Table 3.**)
- *Residental energy consumption*: Literature shows that energy consumption in the residential sector is approximately determined by the total households numbers and their income level. We assume that current supply energy for residential sector is exclusively generated by fossil fuels. Thus if the installed capacity of solar PV energy grows over time, the energy that is produced by fossil fuels could be replaced by the solar PV energy. (See items7 and 8 in **Table 3**.)
- *Residential CO_2 emissions*: CO_2 emissions from energy use in the residential sector is estimated by multiplying the energy use with the residential carbon intensity.CO_2 emissions will be lowered when the number of installed capacity of solar PV energy grows. As a result, the residential carbon intensity is going down gradually. By contrast, the residential carbon intensity is going up gradually in BAU scenario due to an increasing energy consumption. On the other hand solar PV energy will also generate CO_2 emissions although it is not as much as fossil energy does. (See items 9, 10, 11, 12, 13, 14 and 15 in **Table 3**.)
- *Installed capacity of Solar PV power*: this variable is installed Solar PV power generation that generate both energy and CO_2 emission. The number of installed capacity of solar PV power is defined as the initial instalation capacity plus annual installation capacity minus retirement of installed capacity. The variables of solar PV power and solar PV energy shown in the model, are differentiated between generated energy (calculated in Kilowatt) and consumed energy (calculated in Terrajoule).We assume the initial installed capacity is zero, the lifetime of the solar PV system is 20 years, and the installed solar PV power are in operation without stopping over time. (See item 16,17,18 and 19 in **Table 3** and items 3, 4, 5, 6, 7 and 8 in **Table 4**)
- *Installation rate*: We assume three factors influence this variable, i.e., subsidy, householdsincome, and maximum potential capacity of solar PV power in Suita City[3]. Goverment's subsidy for solar PV installation will trigger households to install solar PV system on their home, but it also depends on their income (the variable of households's tendency to use solar PV) and the maximum potential capacity of solar PV power in Suita (the variable of Solar PV power ratio). Next section explains the details of this variable and those three factor. (See item 20,

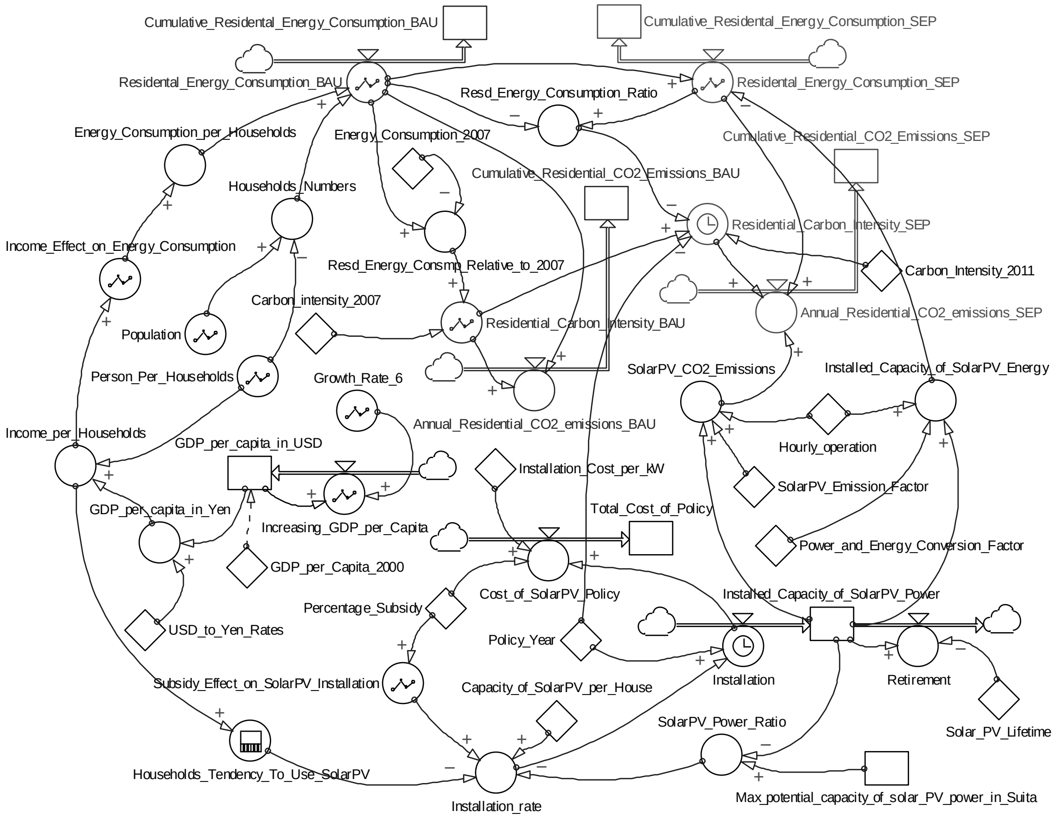

Fig.2 The SD model of this study.

21, 22 and 23 in **Table 3** and items 1, 9, 10, 11 and 12 in **Tabel 4**)

- *Cost of solar PV policy*: This variable is the cost of solar PV policy is correlated with the annual installation capacity of solar PV system. As the number installation grows, the cost of solar PV policy will increase. (See item 16 in **Table 3** and items 9 and 12 in **Tabel 4**)
- *Policy year*: This variable is the time selection for the implementation of Solar PV promotion policy.(See item 13 in **Table 4)**

(2) Simulation Setting

For a subsidy cost of the installation of solar PV system on residential sector in this study, we refer to Japan Photovoltaic Expansion Center[20]. According to them, one-time subsides for purchase and installation of solar PV system is 30,000 yen per kilowatt (kW) if the installation cost is from 475,000 yen to 550,000 yen. Hence, this study set 550,000 yen (¥) as the installation cost per kW with the subsidy of 5.45% (¥30,000/¥ 550,000) per kW.

The effect of subsidy to the annual installation rate for the model follows Zhang et al.[21]. Based on their panel data analysis of an11-year data set on all 47 prefectures in Japan, they found that the presence of subsidy policy induces 98 additional units of the installation of solar PV system. The capacity of solar PV generation systems for residential is typically in the range of 3 to 5 kW per unit house[22]. For this simulation, we set 3.5 kW as installed capacity of solar PV systems per unit house, so that the annual installation rate will be 98 unit x 3.5 kW per unit house = 343 kW. Thus, we assume a linear effect of a subsidy on new installment so that the subsidy with a 5.45% payment will cause annual installation of PV systems equivalent to 343 kW of power generation capacity. The maximun of the linear effect graph is twofold larger than our assumption, that is the subsidy of 10.9% will effect to the annual installation of 686 kW. However, as our assumption that have described previously, the subsidy associated with the annual installation rate in the model is limited by households' tendency to use solar PV and solar PV power ratio. In this model, households' tendency to use solar PV is a proportional between annual income per households and the base value of income per households in 2000. Finally, solar PV power ratio is the ratio between the variables of installed capacity of solar PV power and maximum potential capacity

Table 3 Model equations.

Item	Variable	Equation
1	Population (t)	= GRAPHCURVE(TIME, 2000, 5, [347929, 350920, 351840, 355772, 350417, 341520"Min:300000;Max:400000"])
2	Households numbers (t)	= Population (t) / Number person per households (t)
3	Number person per households(t)	= GRAPHCURVE (TIME, 2001, 1, [2.42, 2.4, 2.38, 2.36, 2.34, 2.32, 2.3, 2.28, 2.27, 2.26, 2.25"Min:0;Max:3"])
4	GDP per capita (t)	= Initial GDP per capita + $\int_0^t \text{Increasing GDP percapita (s) ds}$
5	Income per households (t)	= GDP per capita in Yen (t) x Number person per households (t)
6	Income effect to energy consumption (t)	= GRAPH(Income per households, 6000000, 350000, [0.0368, 0.0369, 0.0374, 0.0377, 0.0378, 0.0379, 0.0382"Min:0.0368;Max:0.0382"])
7	Residental energy consumption BAU (t)	= Households numbers (t) x Energy consumption per households(t)
8	Residental energy consumption SEP (t)	= [Households numbers (t) x Energy consumption per households(t)] – Solar PV energy installed capacity (t)
9	Residential CO_2 emissions BAU (t)	= Residental energy consumption BAU (t) x Residential carbon intensity BAU (t)
10	Residential carbon intensity BAU(t)	= IF(TIME>=2008, Energy consumption relative to 2007 (t) x Carbon intensity 2007, GRAPH(TIME, 2000, 1, [64.91, 63.07, 62.45, 62.28, 76.94, 77.1, 73.76, 78.91"Min:60;Max:80"]))
11	Energy consumption relative to 2007 (t)	= Residental energy consumption BAU (t) / Energy consumption 2007
12	Residential CO_2 emissions SEP(t)	= [Residental energy consumption SEP (t) x Residential carbon intensity SEP (t)] + Solar PV CO_2 emissions (t)
13	Residential carbon intensity SEP (t)	= IF(TIME>=Policy year, Carbon intensity 2011 x Residential energy consumption ratio (t), Residential carbon intensity BAU (t))
14	Residential energy consumption ratio (t)	= Residental energy consumption SEP (t) / Residental energy consumption BAU (t)
15	Solar PV CO_2 emissions (t)	= Installed capacity of solar PV power (t) x Hourly operation x Solar PV emission factor
16	Installed capacity of solar PV power (t)	= Initial installed capacity + $\int_0^t \text{Installation (s) ds} - \int_0^t \text{Retirement(s) ds}$
17	Installation (t)	= STEP(Installation rate (t), PolicyYear)
18	Retirement (t)	= Installed capacity of solar PV power (t) / Solar PV lifetime
19	Installed capacity of solarPV energy (t)	= Installed capacity of solar PV power (t) x Hours per year x Power and energy conversion factor
20	Installation rate (t)	= Capacity of Solar PV per house x Effect subsidy on Solar PV diffusion in unit x Households tendency to use solar PV (t) x [1–Solar PV power ratio (t)]
21	Households tendency to use solar PV (t)	= Income per households (t) / Base income per households (in 2000)
22	Solar PV power ratio (t)	= Installed capacity of solar PV power (t) / Maximum potential capacity of solar PV power in Suita City
23	Cost of solar PV policy (t)	= Installation cost per kW x Percentage subsidy x Installation (t)

of solar PV power in Suita City. This variables is like a carrying capacity in the environmental field:the installed capacity of Solar PV power must be less than or equal to the maximum potential solar PV power in Suita i.e. 1416 Terrajoule (TJ) or 44901.07 kW[3]. As described earlier,we used GDP per capita to estimate the average income of every households in Suita. To extrapolate the future GDP per capita, we conducted random simulation by using the highest and lowest of Japan's GDP growth rate during the period 2000 to 2011[19].

In order to see the effectiveness and efficiency of the policy implementation, we assume the initial installed capacity of Solar PV system in Suita City is zero. Although based on the data of METI-Kansai, installed capacity data of Solar PV Power until 2010 is 636 unit or 2256 kW[23]. Since we also assume the implementation of the policy in Suita started from 2011, we did not take into account the installed capacity before the policy is implemented.

Finally, we assume that those trends will not change over time until the rest of simulation time that is 2020 (Stage-I of Suita's plan on a low carbon society). The parameter values for this model are

Table 4 Parameter values for simulating the model.

Item	Parameter	Value
1	Initial GDP per capita (in 2000)	$37291.7[19]
2	GDP per capita growth rate (random simulation)	-5.4% ~ 4.5%[19]
3	Initial installed capacity of solar PV power	0
4	Solar PV lifetime	20 years[24]
5	Hourly operation	1year = 8760 hours
6	Maximum potential capacity of solar PV power in Suita City	1416TJ = 44901.07 kW[3]
7	Power and energy conversion factor	1 kWh = 3.6 $x10^{-6}$ TJ[25]
8	Solar PV emission factor	32 $x10^{-6}$ ton[26]
9	Percentage subsidy	5.45 %[20]
10	Effect subsidy on solar PV installation	98 unit[21]
11	Capacity of solar PV per house	3.5 kW[22]
12	Installation cost per kW	¥550000[20]
13	Policy year	2011

listed in **Table 4**.

4. SIMULATION RESULTS AND DISCUSSION

This section reports and discusses the simulation results of scenarios, addressing energy consumption, CO_2 emissions, and the implementation cost of Solar PV promotion policy.

(1) Simulation Results of Solar PV Promotion Policy

Fig.2 and **Fig.3** show the simulation results of BAU and SEP scenarios for energy consumption and CO_2 emissions for both historical data and extrapolation. Since the latest available data of energy consumption and CO_2 emissions of Suita is only available until 2007[3], the extrapolation of scenarios in this study starts from 2008. Based on the simulation results, without any policy intervention (BAU scenario) CO_2 emissions in residential sector in 2020 will reach 524388.30 ton. Given that CO_2 emissions in residential sector in 1990 was 338000 ton[3], CO_2 emissions in 2020 will become1.55-fold relative to 1990 level under the BAU scenario.

The integration of quantitative simulation results from the simulation graphs in **Fig.2** and **Fig.3** is depicted by bar chart in the **Fig.4**. The reduction of energy consumption and CO_2 emissions does not seem significant since the length time of implementation policy is only 9 years (2011 to 2020) and since we just assume to follow the government subsidy standard. **Fig.4** has shown comparison simulation results of BAU and SEP scenarios that the total energy saving by installation of solar PV system from 2011 to 2020 reaches 356.93 TJ or 99.1472 GWh, while for the total amount reduction of CO_2 emissions reaches 151,523.96 ton, and Suita City should spends over ¥87.4 million for the renewable energy promotion of Solar PV system during the promotion period.

Based on the total cost of the subsidy and the total CO_2 emissions reduction, we can calculate the cost of the CO_2 emissions reduction per ton by the total cost of the subsidy (¥87.4 million) divided by the total CO_2 emissions reduction (151,523.96 ton). Thus, the policy cost per ton of CO_2 emissions reduction is ¥577.39 per ton CO_2. This reduction cost is lower than the carbon prices to eliminate most carbon emissions from power generation. According to Intergovernmental Panel on Climate Change (IPCC)[27], those reduction costs were estimated in the range of \$20 to \$80 per ton CO_2 or ¥1600 to ¥6400 per ton CO_2, assuming that \$1 is equal to ¥80. Thus, interms of reduction cost, the renewable energy promotion policy through a subsidy for solar PV generation systems is still a promising way to realize

−1− BAU scenario −2− SEP scenario

Fig.2 The energy consumption of BAU and SEP scenarios.

Fig.3 The CO_2 emissions of BAU and SEP scenarios.

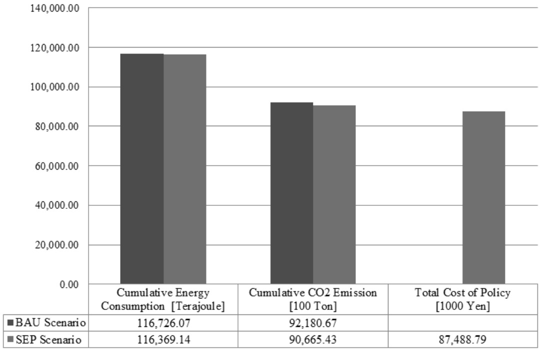

Fig.4 The integration of quantitative simulation results of BAU and SEP scenarios from 2000 to 2020.

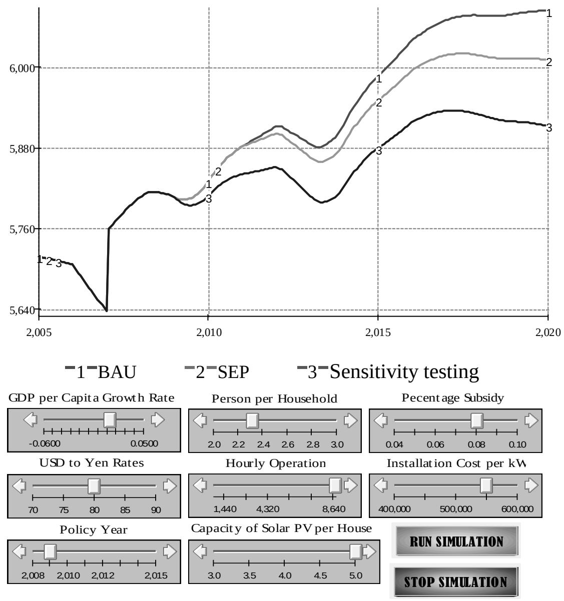

Fig.5 Sensitivity analysis result of the energy consumption.

a low-carbon society.

(2) Model Validation and Experiment

For exploring the model in order to get new insight and better understanding about the policy implementation, the model is presented in simple SD management flight simulators for interactive experimentation (**Fig.5**). We selected several variables that will be under user control to change the scenario by adjusting the value input for the model. We also used the management flight simulators to test the model to build convidence.

Sensitivity analysis testing was conducted by changing the scenario to see numerical sensitivity, behavior sensitivity and policy sensitivity of the model. For the new scenario, we assume that the implementation of solar PV promotion policy will be started in 2009, the subsidy fee for installation is 8% and capacity solar PV system per house is 5 kW (uses maximum capacity). **Fig.4** shows the results of a sensitivity analysis. If we compare the Sensitivity testing scenario to BAU scenario, the total energy saving by installation of solar PV system from 2009 to 2020 reaches 1045.23 TJ or 290.34 GWh, while for the total amount reduction of CO_2 emissions reaches 263691.03 ton, and the Suita City will spent over ¥311.9 million for the renewable energy promotion of Solar PV system during the promotion period. Thus, the policy cost per ton of CO_2 emissions reduction is ¥1182.82 per ton CO_2.

From the test, we can see that numerical values, behavior generated by the model, and policy implications have changed significantly and to follow basic pattern. Thus, we can ensure that the model is sensitive to the changes under uncertain parameter inputs and the policy recommendation of SEP scenario is sensitive to plausible variations in assumptions. This test also reconfirmed the previous results that the renewable energy promotion policy through a subsidy for solar PV generation systems is still a promising way to realize a low-carbon society. Although we have extended the period of policy implementation (2009-2020), increased the subsidy cost (8%) and used the maximum capacity of solar PV generation systems per house (5kW), the reduction cost of CO_2 by promoting solar PV system is still in the range of IPPC's suggestion for eliminating carbon emissions from power generation.

5. CONCLUSION

This study provides cost-benefit evaluation by using SD approach to analyze the promotion of renewable energy policies uses the Suita City's residential sector as the case study. The simulation results show that the promotion of the solar PV for residential can be an effective measure to conserve energy and mitigate CO_2 emissions for the Suita City.

We address that the model is not meant to predict the future situation or to produce the quantitative figures that is less or more will be same with the actual situation in the future. The main objective of this initial model is to promote learning by experiments (simulation) to get insights into and understanding about the implementation of Solar PV promotion policy and its interaction with the socio-economic situations in the city.

Future work is to expand the model that includes industrial, business and transport sectors and more scenario alternatives with considering more policy instruments as well as different technologies related to renewable energy and efficient energy use.

Furthermore a participatory modeling in order to obtain different perspectives from different stakeholders from the initial stage of modeling process is also important.

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