Reduction Potential of CO_2 Emissions by Installing Photovoltaic Power System on Buildings and Unused Land in Nagoya City

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1 Introduction

Installing photovoltaic power system has been urged as one of measures for low carbon society, as can be seen from "the New Buyback Program for Photovoltaic Electricity", which was launched in November 11, 2009. On the other hand, more functional and effective urban structure has been considered because a renewal period of buildings constructed from the end of Second World War is reached today. In addition, due to the decline of residential housing demand driven by population decrease and demographic aging, unused land has been increasing. To mitigate the environmental load, it is important to consider the efficient use of unused land.

Therefore in this paper, reduction potential of CO_2 emissions on Nagoya city is estimated under scenarios of changes of three-dimensional structure of building and its location according to changes of urban spatial structure and installation of the PV system on building roof and unused land.

2 Methodology

Now, framework of the research model is explained. First of all, movements of population and household in the city is estimated by cohort analysis method and household head ratio method, and data of building type is collected per mesh on the basis of existing data and the movement. Secondly urban spatial structure is constructed by various scenarios with consideration of building life-cycles, and energy consumption and CO_2 emissions are estimated afterward. Finally electricity output in PV system installed on building roof and unused land is estimated, and afterward the reduction effect is evaluated by comparing it with earlier estimated energy consumption and CO2 emissions. About detail of methodology to estimate above population and household and residential housing and commercial buildings, the study of Onishi and other members (2009) is recommended to be referred.

2-1 Estimation of the Area of Building Roof and Unused Land

Building roof and unused land are chosen as places to install PV panels. Area of building roof is estimated with building area as it. But in case that vacant house occurs in the future, its building area is not counted because there is no power demand. On the other hand, area of unused land is expressed as site area calculated by multiplying surplus building area, which occurs in case of residential housing and commercial buildings decrease in future population and household, by building coverage on the basis of area of unused land of the condition of urban land use of City planning Basic Survey (2003) in 2000.

2-2 Estimation of Energy Consumption and CO_2 Emissions

Energy consumption and CO_2 emissions of each year is expressed by the following formula.

$$E_i = \sum_{j=1}^{j}\sum_{k=1}^{k} H_j \times Fr_{j,k} + \sum_{l=1}^{l}\sum_{k=1}^{k} S_l \times Fb_{l,k} \quad (1)$$

$$C_i = \sum_{j=1}^{j}\sum_{k=1}^{k} H_j \times Fr_{j,k} \times G_k + \sum_{l=1}^{l}\sum_{k=1}^{k} S_l \times Fb_{l,k} \times G_k \quad (2)$$

E : Total Energy Consumption (MJ), C : Total CO_2 Emission, Fr : Energy Intensity of Residential Sector, Fb : Energy Intensity of Business Sector, G : CO_2 Emission Intensity, H : Gross Floor Space of Residential Housing, S : Gross Floor Space of Business Building, i : Mesh, j : Housing Structure (Single or Multi-Family), k : Energy Source (Electricity, City Gas, LPG, Kerosene, and Other), l : Types of Business (Office buildings, Wholesale and Retail Industries, Restaurants, Schools and Experiment and Research Institutes, Hotels and Inns, Hospitals and Medical Relating Industries, and Other Service Businesses)

Now, first term of formula (1) and (2) show s residential sector and second term of the formula does show business sector.

In estimation of energy consumption, energy intensities on the basis of gross floor area of building are used, which are expressed as MJ/m^2. In the energy intensities, values of energy consumption questionnaire survey of building sector of The Institute of Energy Economics, Japan (1998) is used. In estimation of CO_2 emissions, CO_2 emission intensities by energy source are used, which are expressed as kg- CO_2/MJ.

2-3 Estimation of Energy Production of Photovoltaic Power System

Output by photovoltaic power of each year is expressed by the following formula.

$$GE_i = R_i \times A_i \times Ef \quad (3)$$

GE : Generation Output (MJ), R : Solar Radiation, A : Footprint of panel, Ef : Conversion efficiency, i : Mesh

The solar radiation is estimated by radiation

calculation model of Arc-GIS. Also, conversion efficiencies of panel are set to 0.1 in both building roof and unused land. Footprints of panel are, in case that it is installed on building roof, set to 37 percent of its area and, in case that it is done on unused land, done to 50 percent.

A gotten output in building roof in that time is used to subtract from lighting and motive power of energy consumption by mesh. On the other hand, that in unused land is done to allot that in the whole Nagoya city to rate of lighting and motive power of energy consumption of each mesh to subtract from the lighting and motive power of energy consumption by mesh.

2-4 Scenario Settings

Scenario of restructure of urban space is set to two patterns, namely centralization and BAU. The centralization means “poly-centralization” that buildings are centralized around train stations. In “poly-centralization”, area of radius of 500 meters covering all station in the city is set and all mesh included this range is covered.

In centralization scenario, households whose place of residence moves with replacement of dwelling are set so that they certainly move to multi-family dwellings of centralizational district. On the other hand, in BAU scenario, the households are set so that they certainly dwell to same type of dwellings in same mesh in case of the replacement. But degree in which households choose dwelling district can be adjusted at our discretion. In this paper, it is adjusted to strikingly show difference between centralization and BAU as an above.

In addition, scenarios by the changes of urban spatial structure and installing PV system are shown in table 1.

3 Results and Discussion

Results in 2050 are shown on all scenarios in table1.

We find that to install PV system on building roof is effective in case of BAU, while to install PV system on unused land is effective in case of centralization. In addition, comparing case of BAU and installing PV system on building roof, namely scenario 3, with case of centralizing urban structure, namely scenario 2, reduction effect of CO_2 emissions in scenario 3 is higher. From the result, promoting installing PV system is more effective than the change of urban structure. However, it is shown that if PV system is installed in newly built stage in dwelling and in 2050 in business buildings. Therefore, it is possible that centralizing of urban structure is more effective, by degree of the installing it. Moreover, high reduction effect of CO_2 emissions is gotten by doing centralization and installing PV system on unused land, namely scenario 6. Therefore, it is possible that the measure is more effective than BAU and installing PV system on building roof, namely scenario 3 by degree of installing it and centralization. In the future, I hope to further examine effect in case that degree of installing PV system and centralization is changed like that.

4 Conclusion and Future Works

In this paper, reduction potential of CO_2 emissions in case of installing PV system as a renewable energy is estimated with the target of achieving a low carbon city. By this study, it is possible to examine future urban structure, effective use of unused land and possibility of installing PV system for realization of low carbon society in urban development.

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References

1 Akio Onishi, Yosuke Takahira, Osamu Higashi, Hiroki Tanikawa, Hidefumi Imura (2009): Future scenarios analysis of CO_2 emission from residential and commercial sectors of Nagoya city. Proceedings of 37th Annual Meeting of Environmental Systems Research 2009, pp.351-358.

2 Environment Bureau of Nagoya City Government: The condition of urban land use of City planning Basic Survey In 2003

3 The Institute of Energy Economics, Japan: Energy consumption questionnaire survey of building sector.

4 Wataru Masuo, Hiroki Komine (2008): Study on the Energy Conservation with the Solar Array and the Solar Collector for Domestic Hot Water Installed on the Roof of a Detached House Built in Built-up Area. Transactions of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, No.134, pp.47-51.

Table 1 Scenarios on urban structure and installation of PV system and the results in 2050 by them

Scena-rio	Urban Structure	PV system		CO_2 Emissions (One Thousand ton)		CO_2 Reduction Rate (%)
		Building Roof	Unused Land	In 2000	In 2050	
1	BAU	×	×	6719.5	6180.9	8%
2	Centralization	×	×	6719.5	5823.6	13%
3	BAU	○	×	6719.5	5239.4	22%
4	Centralization	○	×	6719.5	5260.7	22%
5	BAU	×	○	5974.5	5742.2	15%
6	Centralization	×	○	5974.5	3825.9	43%
7	BAU	○	○	5974.5	4800.7	29%
8	Centralization	○	○	5974.5	3263.0	51%

＊Rate installed PV system on unused land is set to 50 percent.