DEVELOPMENT OF A METHOD FOR ESTIMATING BUILDING PHOTOVOLTAIC POTENTIAL USING 3D URBAN MODEL (PLATEAU)

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ABSTRACT: In October 2020, the Japanese government declared its goal of achieving carbon neutrality, which means zero greenhouse gas emissions by 2050. In 2022, the Tokyo Metropolitan Government passed an ordinance to mandate the installation of photovoltaic panels on new buildings, including single-family homes, from April 2025, the first time in Japan. In 2022, the Tokyo Metropolitan Government enacted the first ordinance in Japan to mandate the installation of photovoltaic panels on new buildings, including detached houses, starting in April 2025. With the enactment of this ordinance in Tokyo, similar trends are expected to accelerate nationwide in the future. In this study, we developed a method to estimate the amount of electricity generated by solar power in detached houses by using PLATEAU data and residential map data. As a result, it was possible to calculate the amount of power generation in detached houses. Therefore, by estimating the amount of power consumed by each household and comparing it with the amount of power generated, we were able to determine how much power consumption can be covered by the installation of photovoltaic panels in each household. The results are compared with the amount of power generated by each household to determine how much power consumption can be covered by installing solar panels.

1. INTRODUCTION

1.1 Background

In October 2020, the Japanese government declared its goal of achieving carbon neutrality, which means zero greenhouse gas emissions by 2050 Carbon dioxide accounts for 85% of greenhouse gas emissions in Japan. Therefore, reducing carbon dioxide emissions is directly related to reducing greenhouse gas emissions. Therefore, reducing electricity consumption, which contributes significantly to carbon dioxide emissions, can contribute to reducing greenhouse gas emissions in Japan. Therefore, the Tokyo Metropolitan Government is promoting the increased use of renewable energy sources to reduce greenhouse gas emissions, with the goal of achieving carbon half by 2030 and zero emissions by 2050. In 2022, the Tokyo Metropolitan Government became the first in Japan to enact an ordinance requiring the installation of photovoltaic panels on new buildings, including single-family homes, from April 2025. The enactment of this ordinance by the Tokyo Metropolitan Government is expected to accelerate similar trends nationwide in the future. According to the Ministry of the Environment, the installation rate of photovoltaic panels in single-family homes was only 12.3% in FY2020, and it is difficult to say that the installation of photovoltaic panels is progressing in Tokyo, or even nationwide.

1.2 Previous Studies

Many studies have been conducted on photovoltaic power generation. For example, Narumi et al (2017) point out that improving efficiency by avoiding installation in small-scale, low-efficiency buildings is a very important perspective when considering medium- to long-term policies for the introduction of large-scale renewable energy. In addition, Takada et al (2009) pointed out that tall buildings in the vicinity may affect the air conditioning load and power generation based on a TRNSYS analysis of a nine-building city block model. Furthermore, Kobayashi et al (2013) found that the amount of electricity generated in the suburban residential area was 17 % larger than that in the urban commercial area by considering the solar radiation shielding provided by the surrounding buildings, based on a GIS analysis of two areas (each 500 m square), one in the urban commercial area and the other in the suburban residential area. Irwin, N, B. (2021) examine if spatial spillovers in residential PV system adoptions exist at small scales – specifically within one's nearest set of neighbours – using spatially explicit data on residential PV installations from Baltimore, MD, and find strong evidence for the existence of spatial spillovers, with a neighbouring installation increasing PV system adoption likelihood by 16.5–17.1 percent. Rode J. (2016) employ an epidemic diffusion model which includes a spatial dimension, and control for temporal and spatial heterogeneity. Hwai-Yuan J. (2018) results demonstrate that cities with large population size, municipal utilities, and high proportions of pro-environment, educated constituents are more likely to adopt solar approval processes.

1.3 Objective

On the other hand, there are not many examples of analyses that consider the hours of sunlight for each building. Since the amount of sunlight differs depending on the location characteristics of buildings, it is necessary to estimate the amount of electricity generated based on the amount of sunlight for each building. Even if photovoltaic panels are installed on buildings with uniform specifications, they may not generate enough power in urban areas where the roof area is smaller than in suburban and rural areas, the distance between neighbouring buildings is narrower, and high-rise buildings are distributed in the surrounding area, which may create shade[3)]. As a result, some houses are not expected to contribute to the expected reduction of greenhouse gases. In other words, to study effective GHG emission reduction measures for the entire urban space, it is necessary to establish an environment to estimate the amount of electricity generated and consumed by each building for the entire city.

Therefore, in this study, we will develop a method to estimate the amount of electricity generated on each building by the installation of photovoltaic panels on each building by integration of data on solar radiation and hours of sunlight with Japanese 3D urban model called "PLATEAU" released by the Ministry of Land, Infrastructure, Transport and Tourism in 2020.

2. METHODS

2.1 Data

In this study, we used two kinds of data. First is the 3D urban model called "PLATEAU" of the special wards of Tokyo (hereafter referred to as the "PLATEAU data"), which was made open data by the Ministry of Land, Infrastructure, Transport and Tourism in 2020 as the building model. From this data, we can collect detailed 3D building shape data. Second is the climatological data from the National Land Information System (NLD) developed by Japan Meteorological Agency (hereafter referred to as the "climate mesh data"). From this data, we can obtain average values of sunshine hours and solar radiation for the past 30 years on each 1 km square mesh.

2.2 Creation of data for analysis Data

To determine the roof area, solar radiation, and hours of sunlight of individual detached houses, we first spatially integrated the PLATEAU data with a residential map in 2020 provided by Zenrin Co. Ltd. based on building locations using QGIS. From the attribute of the building polygon data of residential map, we could monitor the building use of each building. Therefore, we extracted buildings whose building use was detached house. The roof area and height of each building were obtained directly from the area and height data in the PLATEAU data. The utility of photovoltaic power generation for each building was clarified by calculating the amount of electricity generated using these values. Finally, the estimated results were analysed and evaluated. The target area of this study was the entire Setagaya Ward, Tokyo (hereafter referred to as "Setagaya Ward"). Setagaya Ward has the largest population and the largest number of households in Tokyo prefecture (approximately 920 thousand people and 490 thousand households) and has a high density of buildings of various sizes. The number of buildings used in the calculation is 153,516 detached houses in Setagaya Ward.

3. ESTIMATION OF POWER GENERATION

3.1 Estimation Method

First, the amount of solar radiation and daylight hours needed to estimate the amount of electricity generated were spatially integrated for each building. Next, we estimated the amount of electricity generated by each building, considering the area of the solar panels installed on each building. Since the required footprint of each house is different, we estimated the amount of electricity generated in three steps: 30%, 50%, and 70% of the roof area. Generally, when estimating the amount of electricity generated by photovoltaic power generation, solar radiation is mainly used to estimate the amount of electricity generated, and the number of hours of sunlight is rarely considered. However, in Setagaya Ward, based on the climate mesh data, the amount of solar radiation is uniform throughout the entire area. However the hours of sunlight vary from place to place. The annual power generation per building (Ep) and the estimated annual power generation per building (Ep_g) were calculated based on the Photovoltaic Power Generation Installation Guidebook, considering the difference in sunlight hours per building. Ep and Ep_g are defined by equation1 and equation 2.

$$Ep = HPK \times 365 \tag{1}$$

$$Epg = EpS \tag{2}$$

Where H, P, and K are the average daily solar radiation, system capacity (kW), and the loss factor (0.73) specified by the Photovoltaic Power Generation Installation Guidebook, respectively. S is the value of the ratio of the sunshine hours of the building to be estimated to the average value for the past 30 years (1991~2020) in Tokyo based on data from the climate mesh data and represents the ratio of sunshine hours for each building.

3.2 Estimated Results

Figures 1, 2, and 3 show the estimated power generation for individual detached houses in the Sangen-jaya Station area, where is one of the busiest shopping district with residential area in Setagaya Ward by footprint area. According to NEDO's Guidance Document for the Installation of Large-Scale Photovoltaic Power Generation Systems , the average power generation per household in Japan is estimated to be about 6,000 kWh. However, Figure 1 show that only a small percentage of detached houses reach the average power generation of 6,000 (kWh) when the installed area is 30%. In other words, to secure an average amount of power generation in urban areas, a somewhat large installation area is required.

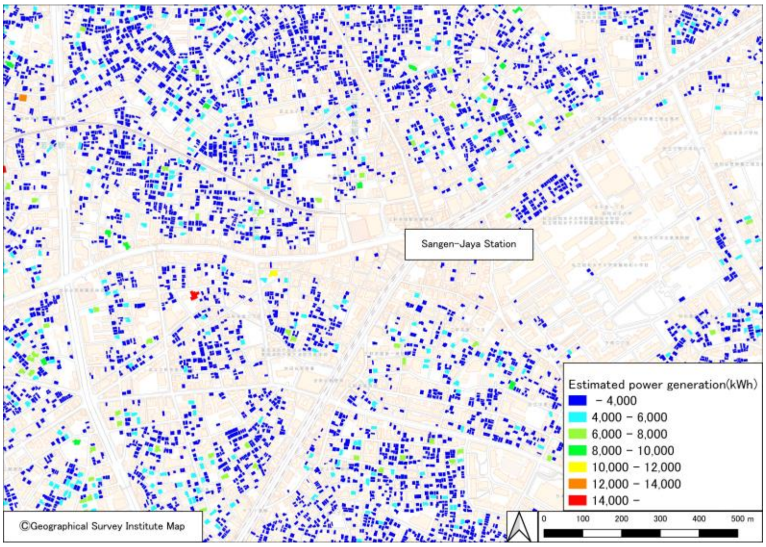

Figure 1. Estimated annual power generation per detached house for 30% of the installed area (Example of Sangen-jaya Station area, Setagaya Ward)

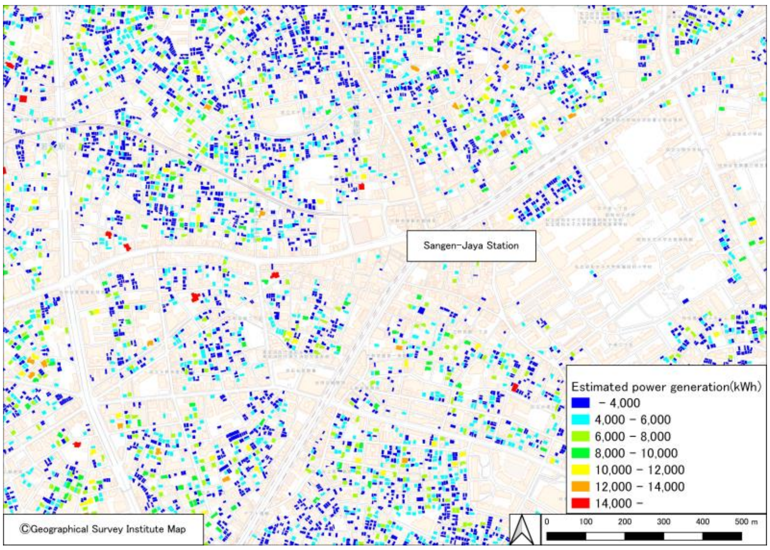

Figure 2. Estimated annual power generation per detached house for 50% of the installed area (Example of Sangen-jaya Station area, Setagaya Ward)

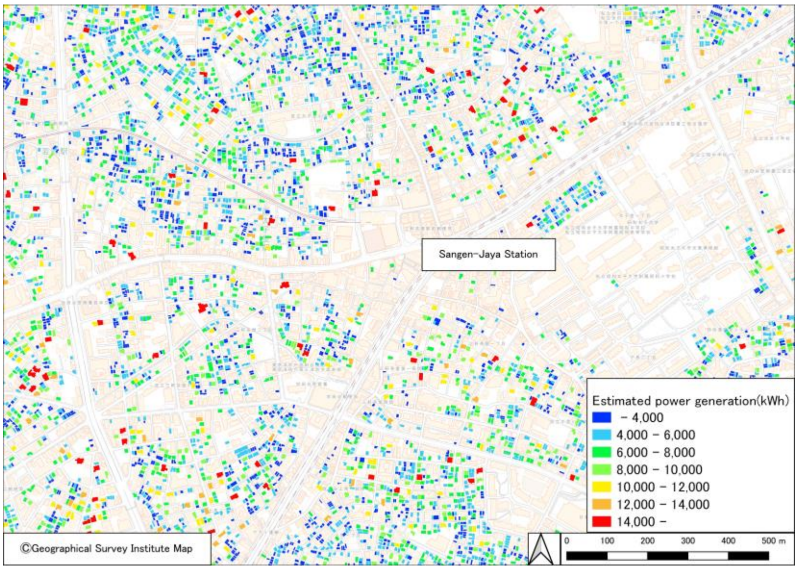

Figure 3. Estimated annual power generation per detached house for 70% of the installed area (Example of Sangen-jaya Station area, Setagaya Ward)

Table 1. Number of buildings by estimated annual power generation (entire Setagaya Ward)

Estimated power generation (kWh)	30% of the installed area		50% of the installed area		70% of the installed area	
	Number of persons in household	Percentage (%)	Number of persons in household	Percentage (%)	Number of persons in household	Percentage (%)
– 4,000	127,836	83.47	73,528	47.90	30,354	19.77
4,000 – 6,000	19,241	12.53	45,870	29.88	52,366	34.11
6,000 – 8,000	4,444	2.89	19,731	12.85	32,261	21.01
8,000 – 10,000	1,318	0.86	7,951	5.18	17,571	11.45
10,000 – 12,000	391	0.25	3,300	2.15	9,742	6.35
12,000 – 14,000	121	0.08	1,516	0.99	4,786	3.12
14,000 –	165	0.11	1,620	1.06	6,436	4.19
Total	153,516	100.00	153.516	100.00	153.516	100.00

4. EVALUATION OF POWER GENERATION

4.1 Power generation per unit of installed area

Figure 4 shows the estimated power generation per unit area which is calculated to divide the estimated power generation by the installed area. It shows that the power generation efficiency is not so different around Sangen-jaya Station. However there are some buildings and areas with high power generation efficiency. In other words, by calculating the amount of electricity generated per unit area, it is possible to identify areas where electricity can be generated efficiently.

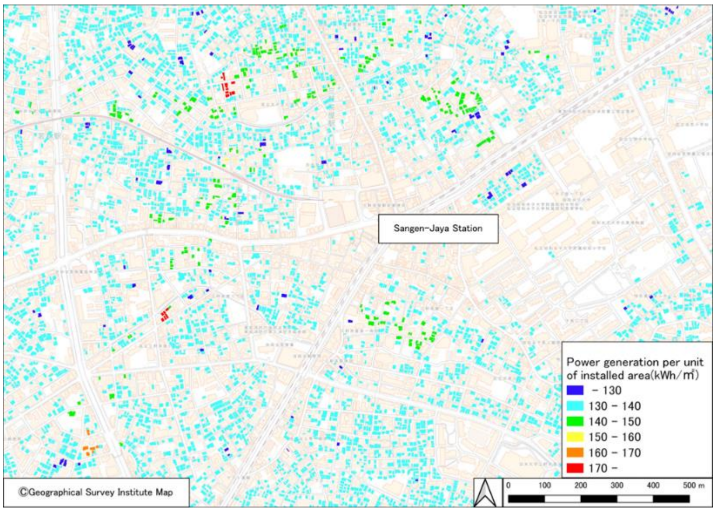

Figure 4. Power generation per unit of installed area
(Example of Sangen-jaya Station area, Setagaya Ward)

4.2 Estimation of energy consumption

To achieve zero emissions, the power consumption of each household should ideally be covered by the amount of electricity generated by photovoltaic power generation. Therefore, we estimated the power consumption of each detached house by giving each detached house an estimated population using the Micro Population Census to develop using the method of Akiyama et al. (2013 and 2019). Using this data, we can monitor estimated number of residents in each individual household. Figure 5 shows the number of households in Setagaya Ward.

Based on the Annual Report of the Family Income and Expenditure Survey of the Statistics Bureau of the Ministry of Internal Affairs and Communications, the national average daily power consumption of a one-person household of Japan is 6.1 (kWh). 2-person household have their power consumption is 1.7 times that of one-person household. 3-person household is 2.0 times, 4-person household is 2.4 times, and 5-person household or more is 2.5 times. Since the amount of electricity consumed in Tokyo, including Setagaya Ward, is approximately 80% to 90% of the national average, the above value multiplied by 0.9 is used as the amount of electricity consumed by an average household in Tokyo. Table 2 shows the amount of electricity consumed according to the number of household members.

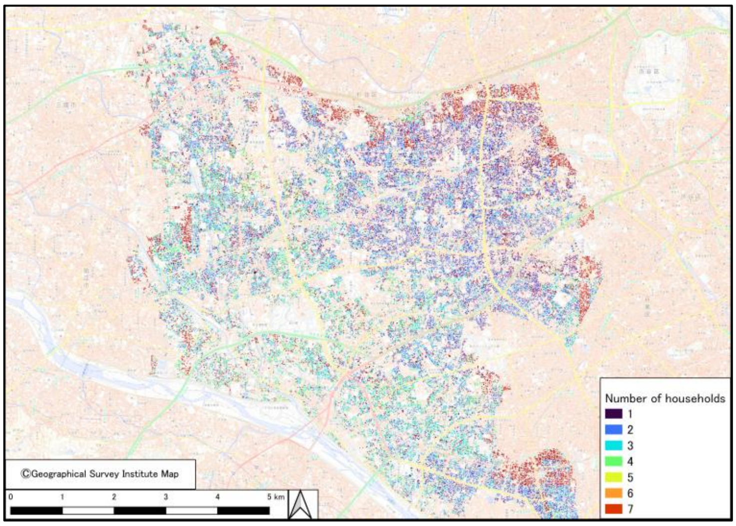

Figure 5. Number of persons living in a detached house in Setagaya-Ward, Tokyo

Table 2. Power consumption based on the number of people in the household

Number of residents	One	Two	Three	Four	More than five
Energy consumption（kWh/day）	5.49	9.33	10.98	13.18	13.73

4.3 Comparison of estimated power generation with power consumption

The estimated power generation as a percentage of estimated power consumption for each detached house is shown in Figures 6, 7 and 8. Tables 3, 4 and 5 show the estimated power generation as a percentage of the estimated power consumption for each detached house and the number of buildings. As Table 5 shows, when 70% of the roof area is covered by photovoltaic panels, most buildings can meet their power consumption with the amount of electricity generated. On the other hand, as Table 3 shows, when only 30% of the roof area is covered by photovoltaic panels, the amount of electricity generated by most buildings cannot cover their power consumption.

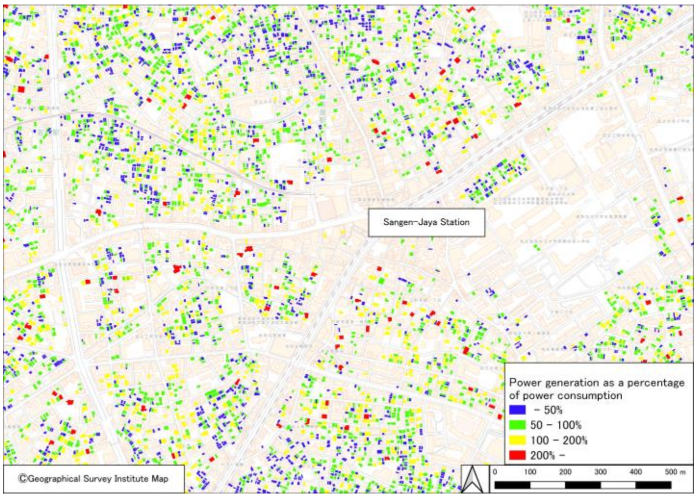

Figure 6. Estimated power generation as a percentage of estimated power consumption for each detached house for 30% of the installed area (Example of Sangen-jaya Station area, Setagaya Ward)

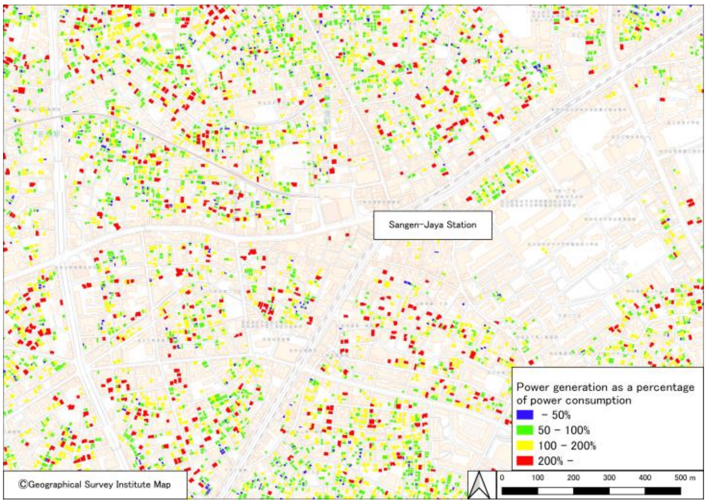

Figure 7. Estimated power generation as a percentage of estimated power consumption for each detached house for 50% of the installed area (Example of Sangen-jaya Station area, Setagaya Ward)

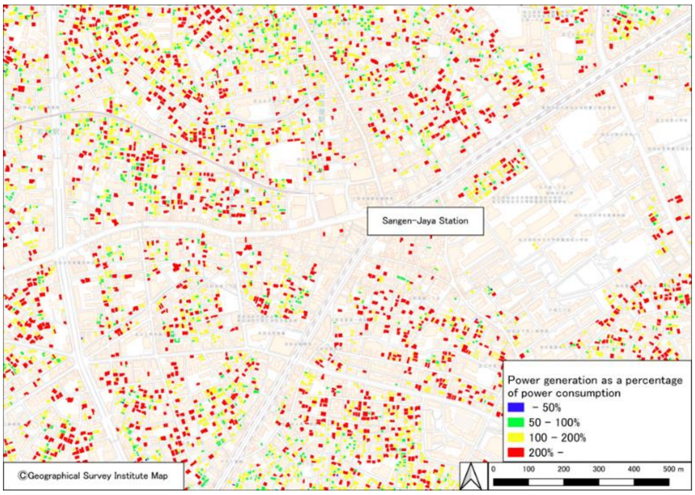

Figure 8. Estimated power generation as a percentage of estimated power consumption for each detached house for 70% of the installed area (Example of Sangen-jaya Station area, Setagaya Ward)

Table 3. Estimated power generation as a percentage of the estimated power consumption for each detached house and the number of buildings for 30% of the installed area (Setagaya Ward)

Power generation / Consumption	Number of persons in household	Percentage (%)
0 – 0.5	45,078	29.36
0.5 – 1.0	72,886	47.48
1.0 – 2.0	30,755	20.03
2.0 –	4,797	3.12
Total	153,516	100.00

Table 4. Estimated power generation as a percentage of the estimated power consumption for each detached house and the number of buildings for 50% of the installed area (Setagaya Ward)

Power generation / Consumption	Number of persons in household	Percentage (%)
0 – 0.5	6,968	4.54
0.5 – 1.0	59,182	38.55
1.0 – 2.0	64,656	42.12
2.0 –	22,710	14.79
Total	153,516	100.00

Table 5. Estimated power generation as a percentage of the estimated power consumption for each detached house and the number of buildings for 70% of the installed area (Setagaya Ward)

Power generation / Consumption	Number of persons in household	Percentage (%)
0 – 0.5	737	0.48
0.5 – 1.0	28,400	18.50
1.0 – 2.0	75,376	49.10
2.0 –	49,003	31.92
Total	153,516	100.00

5. CONCLUSION

In this study, we develop a method for estimating the amount of power generated by installing photovoltaic panels on each detached house by using PLATEAU. The results showed that in Setagaya Ward, the amount of electricity on more than half of the roof area is close to the amount of electricity generated by a typical household. It was also showed that more than half of the detached houses could cover the power consumption by providing more than half of the building area. On the other hand, if only about 30% of the roof area is covered, it is difficult to obtain an amount of power generation on typical household, and it is also difficult to cover the power consumption.

This study assumes that all detached houses are equipped with photovoltaic panels. However, it is difficult to install photovoltaic panels on all detached houses. Therefore, we believe that a more realistic estimation can be achieved by randomly selecting a certain percentage of detached houses to install photovoltaic panels, rather than all detached houses. In addition, by analysing the amount of electricity generated in each municipality based on the amount of electricity generated by a certain percentage of detached houses with photovoltaic panels installed, it is possible to set detailed numerical targets for each municipality to achieve zero emissions. In the future, we would like to set up more realistic scenarios and conduct analysis that will provide useful information for the national and local governments.

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