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GIS-Based Approach for Municipal Renewable Energy Planning to Support Post-Earthquake Revitalization: A Japanese Case Study †

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Abstract: Following a regional-level study conducted in Fukushima Prefecture, Japan (Wang et al., 2014 [1]), this paper presents an approach for municipal renewable energy planning and its experimental application in a Japanese municipality using a Geographic Information System (GIS). The proposed approach is comprised of local issue identification, renewable energy potential evaluation and visualization, site comparison and scenario analysis. GIS was used to analyze and visualize solar, wind and biomass (forest and agriculture residue) potential within Kawamata Town, Fukushima, Japan. According to local conditions, all potential sites were coded and then compared based on different criteria, such as solar radiation, wind speed, slope and land uses, among others. In the scenario analysis section, two scenarios, "renewable energy prioritized" and "evacuation area prioritized", were adopted and compared. The scenarios are altered in terms of placement and the number of renewable energy facilities inside and outside evacuation areas within the town. The results generated through the proposed approach can provide information on local potentials of renewable energy resources, as well as renewable energy development alternatives at the municipal level. They can be used in the interactive dialogue for the municipal renewable energy planning process, to help to fulfill the municipality's post-earthquake energy developmental vision.

Keywords: renewable energy planning; GIS; scenarios; decision making support; post-earthquake revitalization; Japanese municipality

1. Introduction

After The Great North Eastern Japan Earthquake on 11 March 2011, the Japanese Government officially started their Feed-in Tariff (FIT) for Renewable Energy (RE) in July 2012. Incentives from FIT have been expanding the domestic RE markets [2] and enhanced RE's promotion. In 2013, Japan had the third largest annual investment in RE and fuels, as well as the second largest solar PV capacity additions in the world [3].

Fukushima, the most affected prefecture by the great earthquake and its consequent nuclear crisis, has decided to embrace RE as an alternative to nuclear power to improve energy security. The Fukushima prefectural government [4] defined RE as a "new industry" and one of the approaches to support their post-earthquake revitalization. Under Fukushima's big picture for future renewable energy development, municipalities will play a significant role to adopt and refine this vision in various local contexts. Therefore, taking into account the future potential growth of RE in Fukushima, it is necessary to provide strong support for RE planning to achieve its developmental vision, at both the regional and municipal levels.

Spatial planning can help to balance spatial distribution at various scales. To respond to the decentralized distribution characteristics of RE, it is important to integrate spatial planning principals into RE planning [1,5]. This idea has also been addressed in the latest "Conference of the Federal Spatial Planning Ministers (Ministerkonferenz für Raumordnung), Berlin 2015" [6]. In The Netherlands, Province Groningen became the first case where energy was taken into account in spatial planning [7]. At the regional level, the RE planning focuses on mediating RE potential and energy needs for different areas, as well as providing the future RE developmental vision for decision makers. At the municipal level, the planning is more detailed and complex, because many local conditions, such as local RE potential, constrains, land use condition, citizen and stakeholders' interests, among others, should have attention paid to them. This may be the reason municipal energy planning is mainly a bottom-up approach [8], and participatory planning is more popular than rational planning in the municipal energy planning process.

Several authors have focused their attention on the roles of municipal energy plans playing into the national energy transition strategies [9–11], particularly from the RE promotion aspect. For example, Sperling et al. (2011) [9] reviewed 11 municipal energy plans to examine to what extent municipal energy planning matches Denmark's national 100% RE strategies. In the regional energy planning, municipal energy planning is also an essential factor. Brandoni and Polonara (2012) [8] discussed the role of municipal energy planning in the regional energy planning process. Specifically, with regard to municipal energy planning, topics, such as the methodology for energy potential mapping [7], opportunities and challenges in the landscape architecture field [12], local energy-efficient use [13] and case studies from the management and stakeholder participation aspects [14] have been reported. The above studies and practices were centralized in Europe, while this study's field in Asia has been lacking. Previous studies have emphasized the RE potential mapping and social aspects in municipal energy planning. Little attention has been paid to the integrated approach for participatory municipal RE planning. This can provide quantitative and visual information for different local actors. Particularly, earthquake-affected municipalities seeking roads to post-earthquake revitalization can hardly find lessons from which to learn.

In this context, this study aims to establish an informative procedure to support municipal RE planning in the earthquake-affected area. Based on our regional-level study [1], this study adopted a GIS-based approach, which can provide information on local RE potentials, as well as RE development alternatives in the interactive dialogue on the municipal renewable energy planning process and action plan making. The applicability of the proposed approach is demonstrated through the analysis of RE potentials and developmental alternatives within the municipality of Kawamata Town, Fukushima, Japan. The proposed approach features the integration of viewshed analysis for large-sized wind turbines in high wind power potential sites and the consideration of post-earthquake conditions, such as radiation issues and designated evacuation zones within the town.

2. Proposal for a Municipal Renewable Energy Planning Approach

To generate integrated information for decision making for RE planning at the municipal level, we proposed an approach (Figure 1) that is comprised of a set of sequential steps that include:

(1) Local issue identification.
(2) RE potential evaluation and visualization.
(3) Site comparison.
(4) Scenario analysis.

The application of the proposed approach is explained step by step in Section 4.

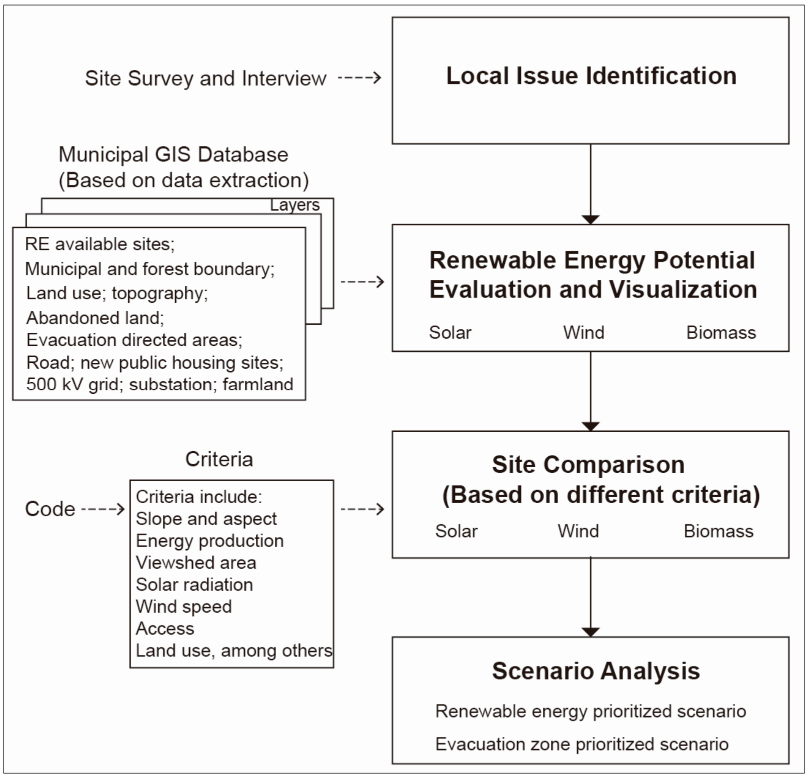

Figure 1. Framework of the proposed approach (source: the authors).

3. Study Area

Kawamata Town is located in the northern region of Fukushima Prefecture, Japan, with easy access to Fukushima City, which is 20 km away (Figure 2). It has a hilly topography, covering an area of 127.66 km^2, with a population of 14,111 (2015). Traditional local industries include: agriculture and silk manufacturing. However, businesses in the town are on the decline due to population loss and aging [15]. The town was designated as a "depopulated area" by the Japanese Ministry of Internal Affairs and Communication in 2002.

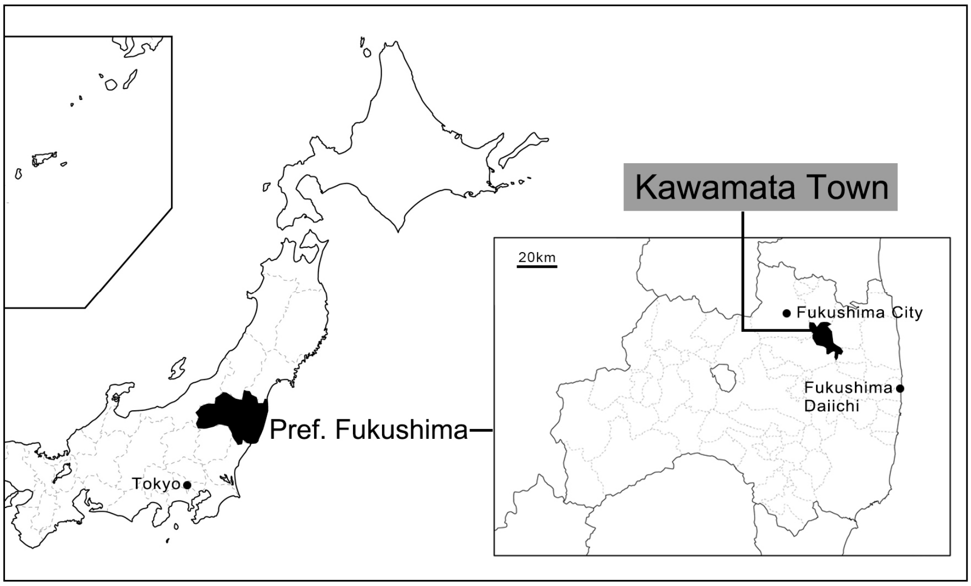

Figure 2. Location of Kawamata Town in Fukushima Prefecture, Japan (source: the authors).

The town has been contaminated by radioactive particles after the Great North Eastern Japan Earthquake and the consequent Fukushima Daiichi nuclear crisis in 2011, especially the southern parts of Kawamata Town (Yamakiya area). This area has high radiation levels; it has been designated as two types of evacuation areas. One is the zone preparing for lifting off of the evacuation directive (<20 mSv/year, after planned decontamination, aiming to rebuild the community several years later), and the second is the habitation restriction zone (>20 mSv/year, aimed to recover as soon as possible for restoration and reconstruction, with residents expected to return) [16]. People who used to live in the evacuation areas have moved out of town or are living in temporary houses within the town. The Fukushima Prefectural Government is now building new public houses for people from the evacuation areas. There will be a total number of 120 households built in Kawamata Town; 40 of them were 24% complete, while 80 were still in the design process [17].

To accelerate the post-earthquake revitalization, the town presented a concept named the "Depopulation Smart Community Project", in cooperation with Toda Corporation [18]. In this project, RE promotion is one of its crucial approaches for revitalization, which includes: five 2-MW wind turbines, five mega-solar farms, a total capacity of 1.5 MW for a factory rooftop PV and 4.0 MW for household rooftop PV.

4. Case Study: Data and Methods

4.1. Local Issue Identification

In the municipal RE planning, the first and fundamental step is to understand local conditions and issues. To identify local issues in Kawamata Town, an on-site survey was conducted from 5–6 July 2014. The survey was composed of site visits and interviews. We visited the rural square temporary houses and the zone preparing for the lifting off of the evacuation directive in Yamakiya area. The first interview respondents included 3 officers from the nuclear emergency response department in Kawamata Town and 5 local citizens. The second interview was conducted with 2 members from the Yamakiya neighborhood association.

4.2. RE Potential Evaluation and Visualization

Following the identification of issues, RE data collection was the next step. Based on the regional RE potential GIS database established in our previous study [1], we found that there are three available RE resources in Kawamata Town: solar power, wind power and biomass. We then extracted their available sites in the database using ArcGIS 10.1 (ArcGIS) (ESRI, Redlands, CA, USA). For usable wood biomass, we selected forest areas under 0.1 μSv/h (air dose rate, 1 m above ground) after the year 2020 as a short-term reference. The RE available potential estimation methods, available site selection criteria and original data resource information can be found in Wang et al., 2014 [1].

To establish a comprehensive GIS database for Kawamata Town, we also clipped other layers based on the regional GIS database. The layers were the Kawamata Town municipal boundary, the Kawamata downtown land use map, topography-hillshade, national forest boundary, protected forest boundary, abandoned land map, evacuation directed area boundary, road, new public housing sites, 500-kV grid, substation and farmland area. See Table 1 for the data sources of the municipal GIS database. The municipal GIS database can provide integrated information for local potential and constraints, thus to support further spatial analysis and decision making in the RE planning process.

Table 1. Data sources for the municipal GIS database.

Category	Relative Original Data	Format/Resolution, or Scale	Data Source
Mega-solar available sites	Solar radiation	Polygon, 1-km mesh	Japanese Ministry of Land, Infrastructure, Transport and Tourism [19]
Wind turbine available sites	Wind speed (70 m) data	Polygon, 500-m mesh	New Energy and Industrial Technology Development Organization (NEDO) [20]
Wood biomass available area (to 2020)	Vegetation (forest)	Polygon, 1:50,000	Biodiversity Center of Japan [21]
	Environmental radiation level	Point data	Nuclear Regulation Authority for Fukushima [22]
Agriculture residue biomass	Farmland area	Polygon, 1:50,000	Japanese Ministry of Land, Infrastructure, Transport and Tourism [19]
Others	Kawamata Town municipal boundary	Polyline, 1:25,000	Geospatial Information Authority of Japan [23]
	Road	Polyline, 1:25,000	Geospatial Information Authority of Japan [23]
	Topography	Raster, 100-m cell size	Japanese Ministry of Land, Infrastructure, Transport and Tourism [19]
	Designated area (national forest boundary, protected forest boundary)	Polygon, 1:50,000	Japanese Ministry of Land, Infrastructure, Transport and Tourism [19]
	Evacuation directed area boundary	JPG	Japan Ministry of Land, Infrastructure, Transport and Tourism [19]
	Land use 2011	Polygon, 1:25,000	Japanese Ministry of Land, Infrastructure, Transport and Tourism [19]
	Abandoned land, 2009	Polygon, 100-m mesh	Japanese Ministry of Land, Infrastructure, Transport and Tourism [19]
	New public housing sites	Text information for addresses	Fukushima Government, 2015 [17]
	500-kV grid and substation	JPG-online map	Fukushima Government, 2013 [24]

4.3. Site Comparison

To compare different potential sites for each Renewable Energy Source (RES), we coded all of the potential sites and then compared them based on different criteria. The results for each criterion were obtained and summarized from the municipal GIS database of Kawamata Town in ArcGIS.

For mega-solar, the sites were coded with a capital letter "S" and a corresponding number. The criteria included: solar radiation, slope and aspect, available land area, current land use, capacity potential, annual electricity production and income estimation based on FIT, access, land use regulation and evacuation zone.

For wind power, the high potential sites were coded with a capital letter "W" and a corresponding number. In consideration of the visual impact of big wind turbines as one of the main factors that influence public acceptance, viewshed analysis was conducted to analyze the visibility of wind turbines on the potential sites using ArcGIS. Viewshed analysis is the analysis of an area to find out whether it is visible or not to a certain observer under different terrain conditions [25]. We carried out viewshed analysis using ArcGIS as follows. First, based on a high potential wind power map, we added wind turbines on different point layers for each site. The wind turbines were assumed as 2 MW wind turbines with a height of 120 m (blade included) and a rotor diameter (D) of 90 m. The number of wind turbines that can be installed on the site was determined by the geographical area of each site. To reduce the array losses and improve energy efficiency, at least a distance of 5-times the rotor diameter (5D) and approximately a 450-m spacing between two turbines is needed [26,27]. Therefore, we used the wind power potential layer's mesh, whose size is 500 m × 500 m. The locations of the wind turbine were determined as the geometric center of each mesh. Second, we ran GIS viewshed analysis (Spatial Analyst Tools-Surface-Viewshed) for each point layer based on hillshade raster data (100-m cell size) and then output the viewshed map for each site. We then calculated visible and non-visible areas for each site. At last, we combined all of the point layers (W1–W11) and ran viewshed analysis again to generate an integrated viewshed map. This integrated viewshed map can show cumulative visual impact areas under the maximum exploitation scenario of local wind power. Criteria for wind power potential sites included: average wind speed at 70 m, slope, potential number of 2 MW wind turbines, annual electricity production and income estimation based on FIT, access, distance from main residential areas, viewshed area, land use regulation and evacuation zone.

For biomass, combined with transportation access and residential area distribution conditions, three specific locations of biomass plants were proposed. The locations were coded with a capital letter "B" and a corresponding number. The criteria for three assumed biomass plants included: available resource land (forest/farmland), current land use, annual heat production and income estimation based on FIT, distance from main resource areas, distance from energy consumption areas, access, land use regulation and evacuation zone.

4.4. Scenario Analysis

In order to evaluate and compare the economic-environmental benefits and impacts under different exploitation extents of RES in the study area, we adopted two RE developmental scenarios. Scenario 1 was the "RE prioritized scenario". This scenario was designed for rational exploitation of RE sources in the study area, with a consideration for balancing development in the evacuation and non-evacuation zones. Five mega-solar farms (2 within evacuation zones), 5 wind turbines (to exploit 20% of the total potential wind turbine numbers, 3 within evacuation zones) and 2 biomass plants (1 within evacuation zones) were proposed in Scenario 1. Scenario 2 was the "evacuation zone prioritized scenario". This scenario was set up to prioritize the exploitation of RES within the evacuation area in Kawamata Town. This is to help with building a more reliable and sustainable infrastructure to attract more people to return to the zone preparing for the lifting off of the evacuation directive area. Two mega-solar farms, 8 wind turbines (to exploit 30% of the total potential wind turbine numbers) and 1 biomass plant located within evacuation zones were proposed in Scenario 2. Five factors to compare Scenarios 1 and 2 were proposed. They include: construction cost, annual electricity production and electricity selling income based on FIT, number of houses to be supplied, viewshed area and CO_2 reduction amount.

5. Results and Discussion

5.1. Local Issues Identification

Based on the site visits and interviews, the following main issues were identified:

- Radiation problems and the decontamination work: according to the local officers, decontamination work was to be completed before August 2014, but people were worried about whether, or to what extent decontamination would work.
- Only aged people are left: after the 11 March 2011 great earthquake, most of the adults and young people moved out; only aged people were left. The traditional "three-generation family" no longer exists in the town. Nobody knows how many people will come back over the years because they fear lifestyle change and that the local infrastructure and services (super markets, medical care, among others) are not fully prepared.
- Big cost and maintenance issue: in regard to Toda Corporation's smart community project, local people were apprehensive about it. They were worried that the high operation cost will make the project difficult to maintain.

The above issues also reflect a general problem in earthquake-affected areas, especially contaminated areas in Fukushima Prefecture. Under the ambitious RE developmental vision proposed by the prefectural government, when it comes to the municipal level, citizens usually get confused about how to achieve it. They usually do not know how much and where the RE potential within the municipality is and what kind of restrictions they should pay attention to, such as land use regulation, radiation condition and protected forest areas, among others. Thus, in order to refine the regional energy developmental vision at the municipal level, it is important to inform local people with quantitative and visual information, so that they can get involved and integrate all of the main actors to develop a more successful municipal RE plan in the participatory planning process.

With regard to the worries about the smart community project initiated by the local government and Toda Corporation, this may be due to the lack of active participation of the local people at the beginning of the project. Participation, whether in the planning stage or the management and maintenance stage, may help to increase people's sensitivity to local conditions, and the sense of involvement could enhance their acceptance of the plan and responsibility to carry it out. In Kawamata Town, local people may think that the project is just a government and big company project; it has little relationship with the local community, which may lead to a lack of local power to ensure that the project is protected from a lack of funding and maintenance issues.

5.2. RE Potential Evaluation and Visualization

Based on the regional RE potential GIS database, local available sites for mega-solar (including abandoned land), wind power, forest biomass (available after the year 2020) and farmland were extracted; see Figure 3. The background figure is the hillshade of Kawamata's topography. Orange is mega-solar potential sites. Red shows abandoned land within the town. Blue stands for available wind power potential (GJ); the darker the blue is, the more potential the area has. Dark green shows the available forest biomass that can be used after the year 2020. Light green shows local farmland area that would provide agriculture residue or have potential for the cultivation of energy crops.

5.3. Site Comparison

5.3.1. Solar

Based on GIS extraction, five mega-solar potential sites in Kawamata Town were identified. S1–S3 are distributed in the north of the town, outside of the evacuation area. S4 and S5 are distributed in the south of the town; both of them were located inside the evacuation area. S4 was located in the zone preparing for the lifting off of the evacuation directive; S5 was located in the habitation restriction zone. See Figure 4. The conditions of the above five sites vary. However, they share similarities, as well: they all have good access and are located outside the urban planning area. The total available land area of five mega-solar potential sites reaches 13.3 ha. Their total annual electricity production and electricity selling income based on the FIT policy reaches 26,272 MWh and 834 M JPY, respectively. See Table 2.

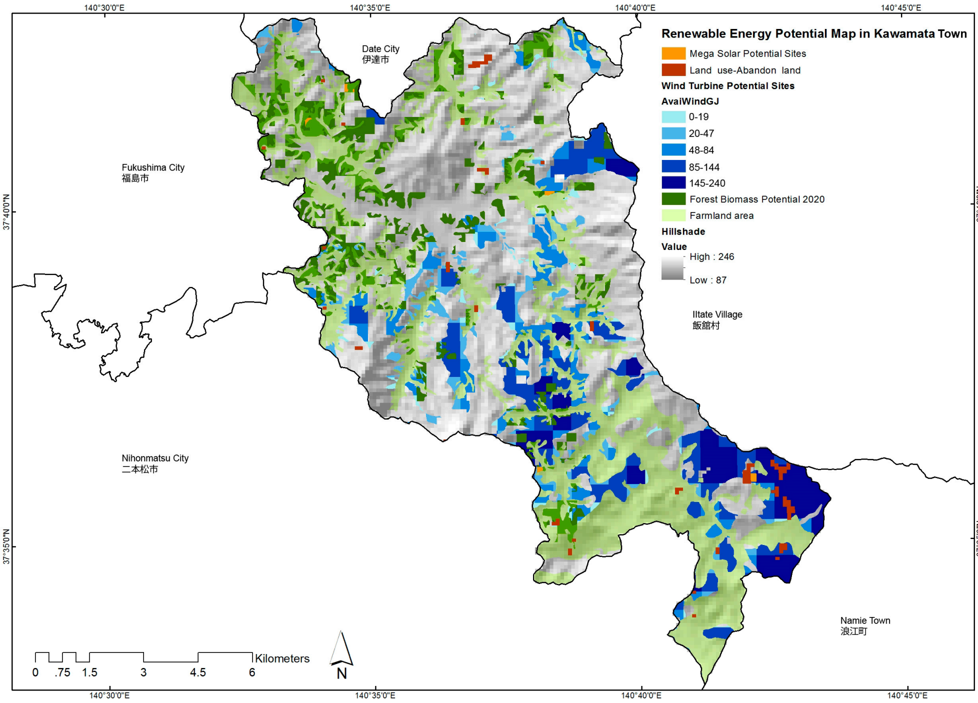

Figure 3. Renewable energy potential map in Kawamata Town (source: the authors).

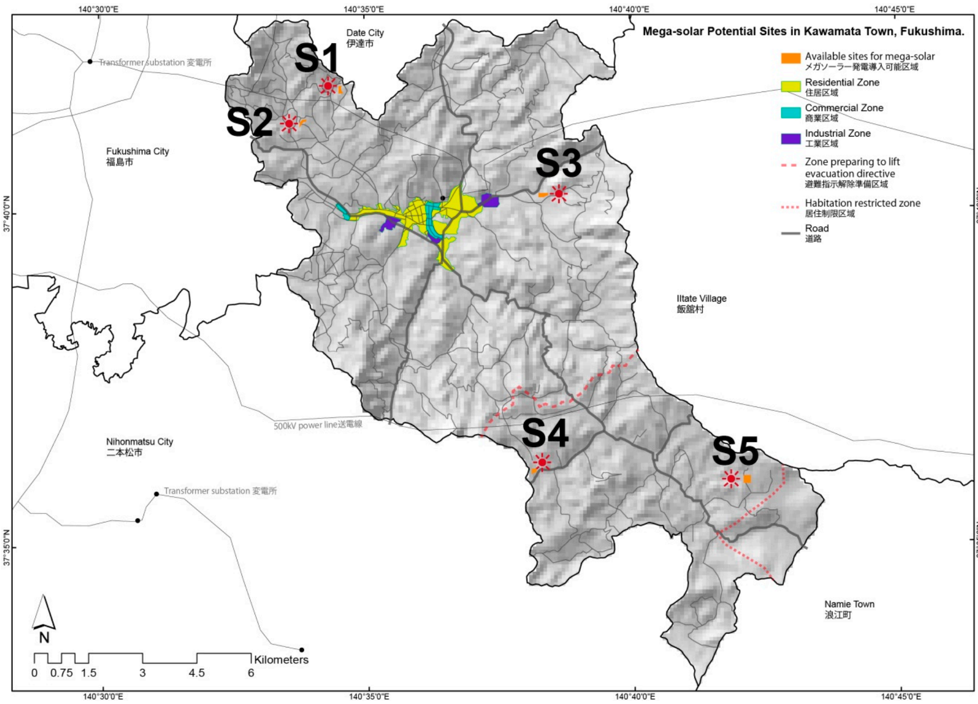

Figure 4. Code numbers for potential mega-solar (S) sites (source: the authors).

Table 2. Detailed information for potential mega-solar sites.

	S1	S2	S3	S4	S5	Total
Average annual solar radiation (MJ/m^2-day)	12.8	12.8	13.0	13.3	13.2	-
Slope aspect	7.5° SW	7.4° S	7.8° W	7.8° SE	6° S	-
Available area (ha)	2.2	1.7	2.6	2.0	4.8	13.3
Current land use	Residence, agriculture field, forest mixed	Mixed	Forest, agriculture field	Factory, decontamination field	Forest, decontamination field	-
Capacity (MW)	2.8	2.1	3.3	2.6	6.2	17.0
Annual electricity production and income	3450 MWh;	2623 MWh;	4170 MWh;	3260 MWh;	12,769 MWh;	26,272 MWh;
	110 M JPY	84 M JPY	130 M JPY	100 M JPY	410 M JPY	834 M JPY
Access	Good	Good	Good	Good	Good	Good
Land use regulation	Outside urban planning area	The same as left	The same as left	The same as left	The same as left	The same as left
Evacuation zone	No	No	No	Yes	Yes	-

As a reference to evaluate the annual electricity production of RE facilities, Kawamata Town's annual electricity consumption was about 106,000 MWh, within which, basic electricity consumption was about 32,000 MWh (about 30%) [18].

5.3.2. Wind

Through extraction of high potential wind power sites (available wind power of 145–240 GJ) based on Figure 3, we found that there were eleven potential wind farm sites. They were mainly distributed in the south of the town. W1–W3 and W5 were located in the north, and they were outside the evacuation area. W4 and W6–W11 were located in the south, and were inside the evacuation area, within which, W4 and W6–9 were in the zone preparing for the lifting off of the evacuation directive. Most of the area of W10 and W11 was distributed in the habitation restriction zone. See Figure 5.

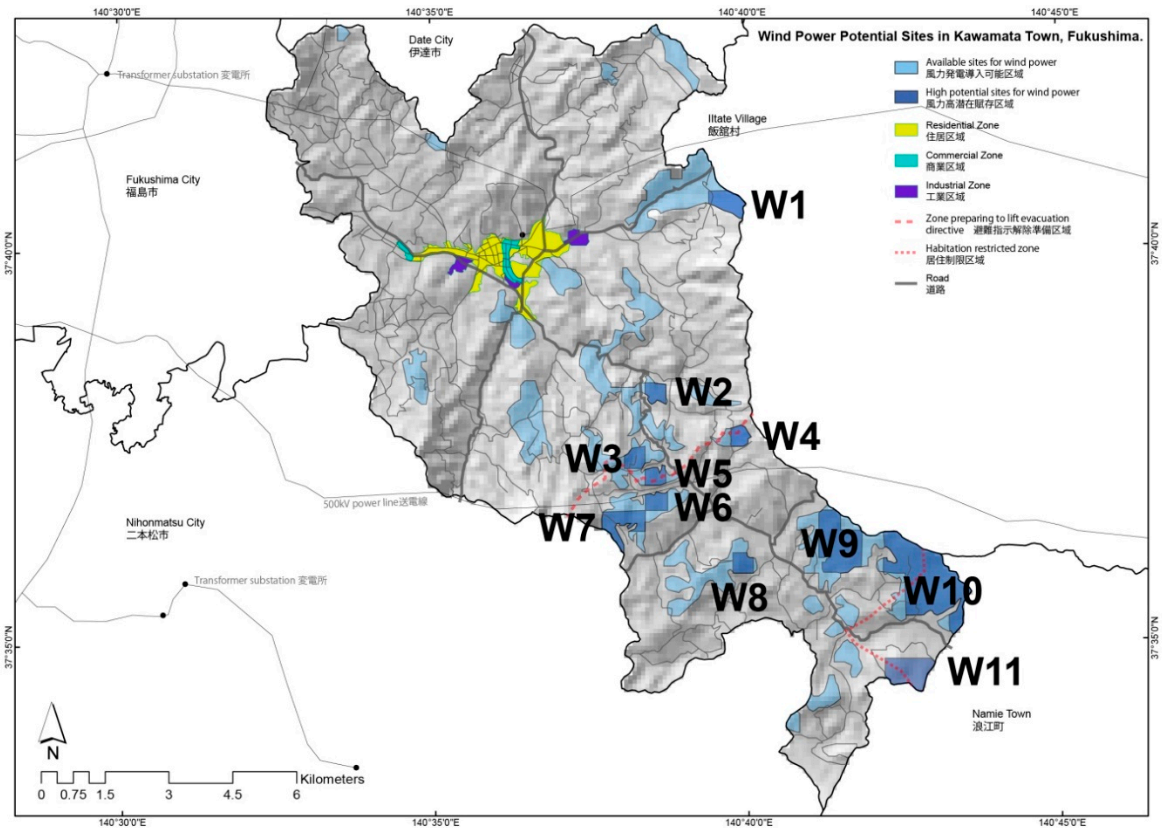

Figure 5. Code numbers for potential wind (W) power sites (source: the authors).

The wind speed conditions were good; the annual wind speeds at 70 m were all over 7.0 m/s. W10 had the largest land area, which can support about 10 wind turbines (2 MW) on the site. The slope conditions were quite different; they varied from 2.8°–13.9°. The land use was mainly forest. Four of them contained houses within; one of them (W10) contained a decontamination working space. All of the sites were located outside of the urban planning area, and they all had good transportation access. Their distance from the closest residential areas varied from 350–3700 m. In total, the annual electricity production from wind turbines can reach 107,921 MWh. This number exceeded the annual electricity consumption (106,000 MWh) in Kawamata Town. Based on the FIT policy, the electricity selling income reached 2362.8 M JPY in a year. See Tables 3 and 4.

Table 3. Detailed information for potential wind farm sites W1–W6.

	W1	W2	W3	W4	W5	W6
Average annual wind speed at 70 m (m/s)	7.0–7.3	7.0	7.2	7.4	7.3	7.4
Slope	13.3°	4.5°	4.2°	8°	2.9°	4.6°–6.9°
Current land use	Forest	Forest	Forest	Forest, houses	Forest	Forest
Number of 2-MW wind turbines that can be installed	2	1	1	1	1	1
Annual electricity production and income	7709 MWh; 170 M JPY	3854 MWh; 84.8 M JPY	3854 MWh; 84.8 M JPY	3854 MWh; 84.8 M JPY	3854 MWh; 84.8 M JPY	3854 MWh; 84.8 M JPY
Access	Good	Good	Good	Good	Good	Medium
Distance from closest residential area	1200 m	700 m	560 m	735 m	350 m	715 m
Viewshed visible area (not-visible) (km^2)	Visible 3.5 (124.2)	Visible 0.5 (127.2)	Visible 1.1 (126.6)	Visible 0.5 (127.2)	Visible 0.5 (127.2)	Visible 0.2 (127.5)
Land use regulation	Outside urban planning area	The same as W1	The same as W1	The same as W1	The same as W1	The same as W1
Evacuation zone	No	No	No	Yes	No	Yes

Table 4. Detailed information for potential wind farm sites W7–W11.

	W7	W8	W9	W10	W11	Total (W1–W11)
Average annual wind speed at 70 m (m/s)	7.0–7.3	7.1	7.2–7.4	7.1–8.2	7.5–8.2	-
Slope	2.8°–8.9°	7.3°–8.8°	3.9°–8.5°	2.8°–13.7°	8.5°–13.9°	-
Current land use	Forest, houses	Mixed land use	Forest, houses	Forest, decontamination field	Forest	-
Number of 2-MW wind turbines that can be installed	3	1	5	10	2	28
Annual electricity production and income	11,563 MWh; 250 M JPY	3854 MWh; 84.8 M JPY	19,272 MWh; 424 M JPY	38,544 MWh; 840 M JPY	7709 MWh; 170 M JPY	107,921 MWh; 2362.8 M JPY
Access	Good	Good	Good	Good	Medium	-
Distance from closest residential area	740 m	860 m	1560 m	3700 m	1500 m	-
Viewshed visible area (not-visible) (km^2)	Visible 3.1 (124.6)	Visible 0.4 (127.3)	Visible 3.9 (123.8)	Visible 10.3 (117.4)	Visible 3.5 (124.2)	Visible 21.4 (106.3)
Land use regulation	The same as W1	The same as W1	The same as W1	The same as W1	The same as W1	-
Evacuation zone	Yes	Yes	Yes	Yes	Yes	-

Exploration of wind power in Kawamata Town would facilitate a transition of the municipal energy structure towards a more sustainable level. The municipality may benefit from RE promotion in support of post-earthquake revitalization through job creation, income increase and environmental education, among others. However, big sized wind turbines bring visual impact to the local landscape. According to the Viewshed analysis results, the location and surrounding topography conditions were different; the visible area of each turbine varied from 0.2 km^2–1.75 km^2 in Kawamata Town. Among them, W6 had the minimum visual impact area for each turbine (0.2 km^2), while W1 and W11 had the maximum visual impact area for each turbine (1.75 km^2). In total, the cumulative visual impact area reached 21.4 km^2. See Tables 3 and 4. Figures 6–9 show the spatial distributions of wind turbines' visual impact area in the town. Green areas were the visible areas of wind turbines, while red areas were the non-visible areas of wind turbines.

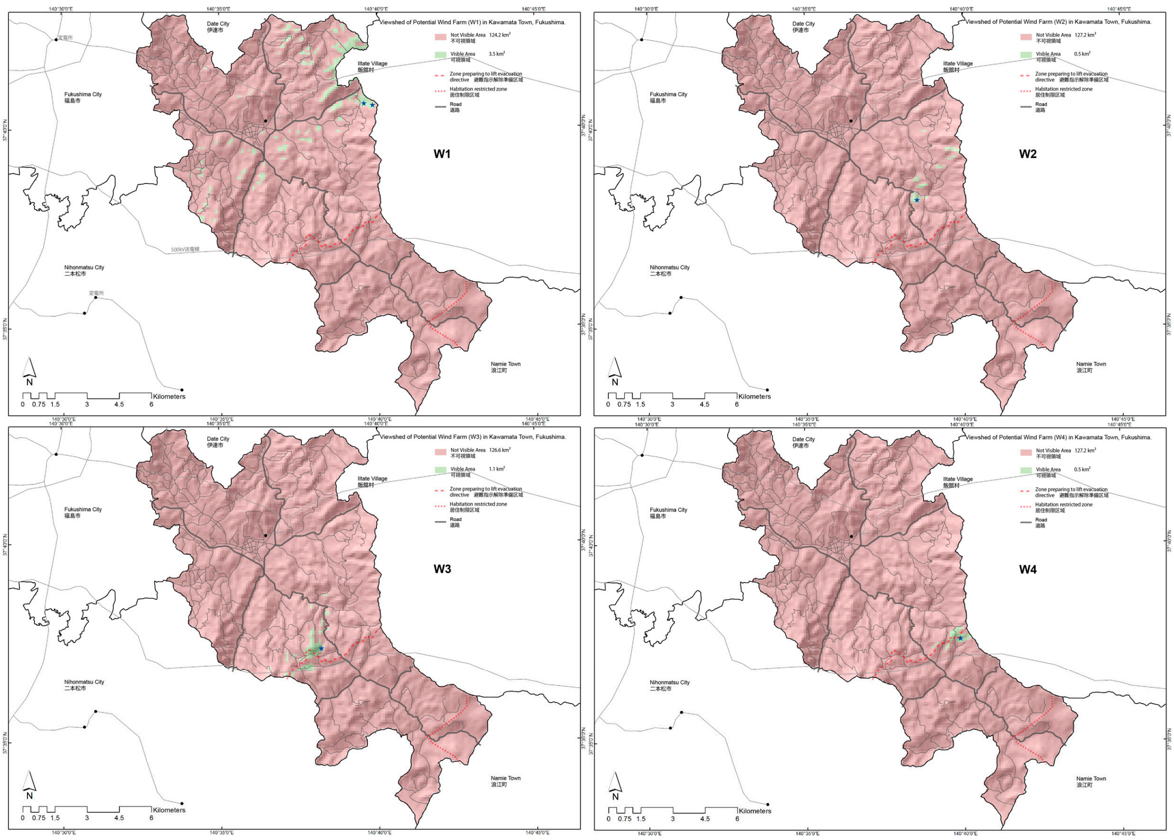

Figure 6. Viewshed maps of the potential wind power sites W1–W4 (source: the authors).

5.3.3. Biomass

Based on the RE potential map (Figure 3), we found that available potential forest for biomass was mainly distributed in the north of the town, while the farmland area that can provide agriculture residue for biomass/biogas was mainly distributed in the Yamakiya area, south of the town. Combined with transportation access and residential area distribution conditions, we proposed three potential sites for the biomass plant. B1 and B2 were located outside the evacuation area. They belong to the non-senbiki urban area (the area that is inside the urban planning area, but neither belonging to the urbanization promotion area, nor the urbanization control area in the Japanese land use planning system). B3 was located in the zone preparing to lift the evacuation directive; its location was outside the urban planning area. The blue arrows show available corridors to transport biomass resources. National forest and protected forest areas that cannot be exploited are shown in the figure, as well. See Figure 10.

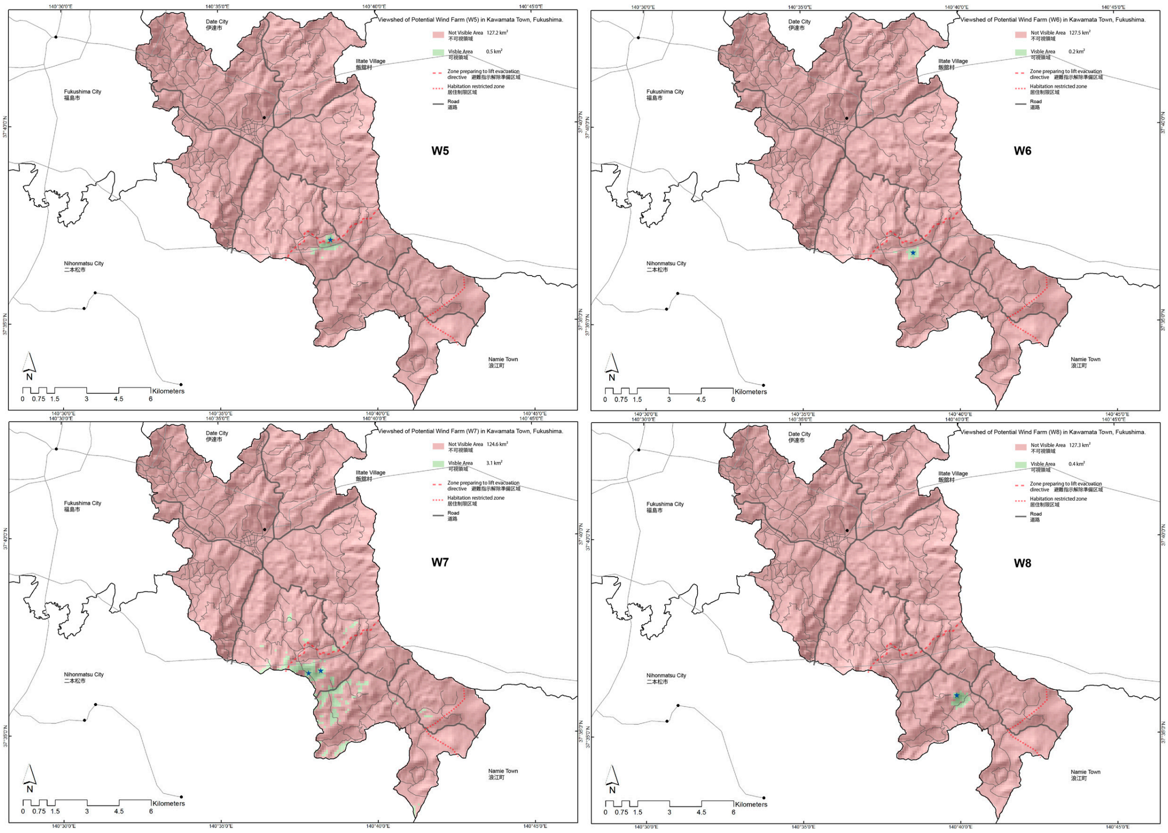

Figure 7. Viewshed maps of the potential wind power sites W5–W8 (source: the authors).

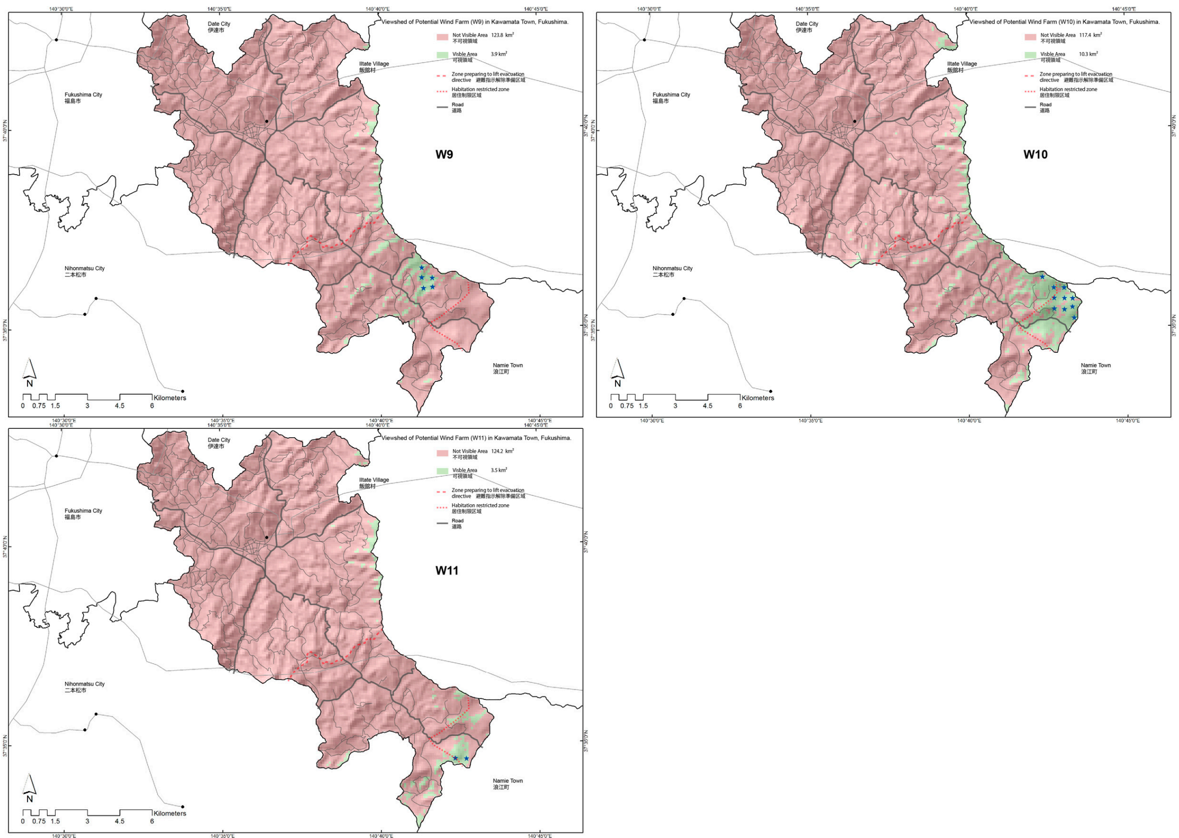

Figure 8. Viewshed maps of the potential wind power sites W9–W11 (source: the authors).

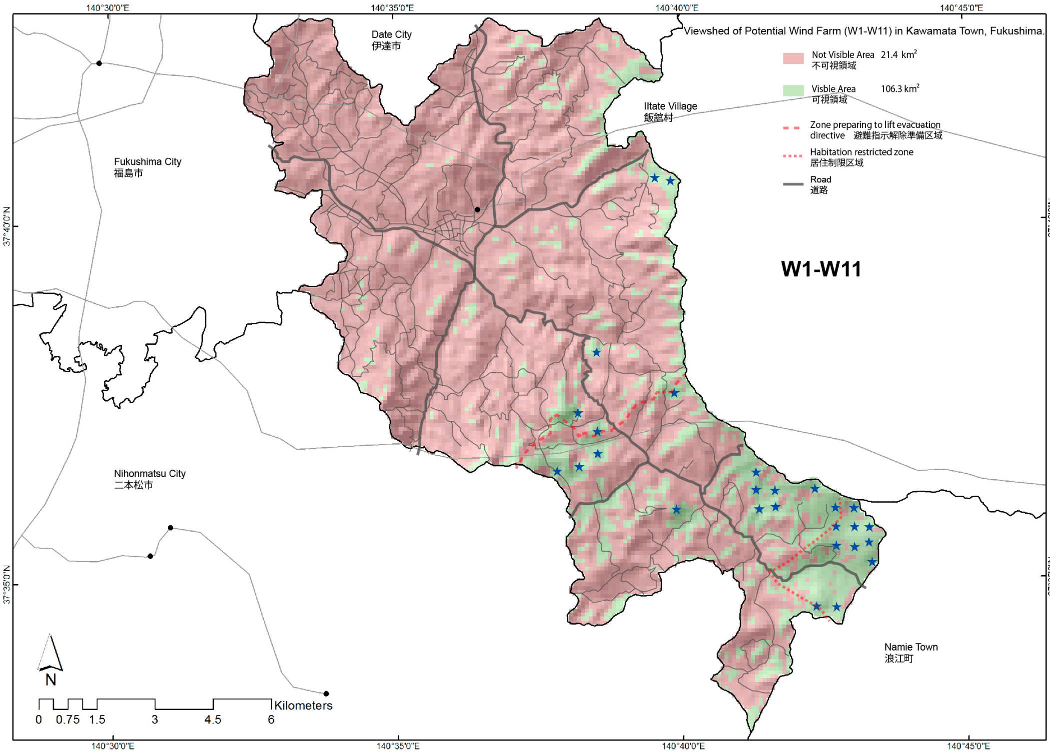

Figure 9. Integrated viewshed map of all potential wind power sites (W1–W11) (source: the authors).

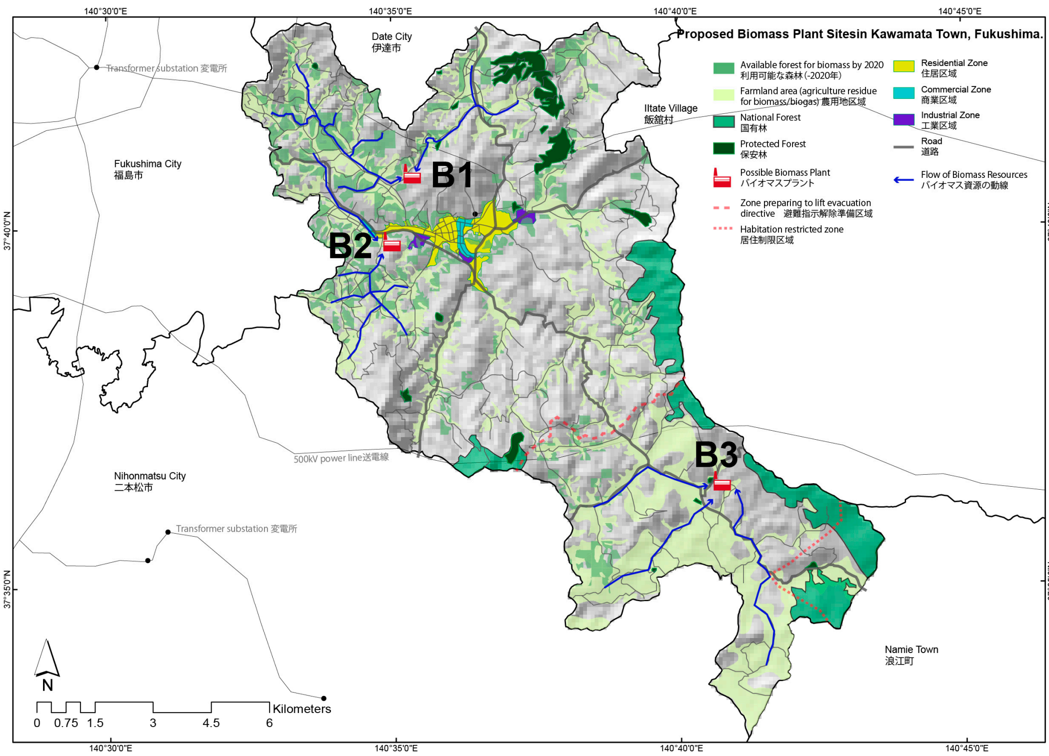

Figure 10. Code numbers for potential biomass plant sites (source: the authors).

Within the municipal area, total agriculture land area was more than the forested area. This can provide 112,030 GJ of heat and bring 746.9 M JPY of income in a year. The proposed biomass plants were located within the distance between 500 and 3000 m from the biomass resource area and 500 and 3500 m from the energy consumption area. They all had good transportation access. See Table 5.

Table 5. Detailed information for potential biomass plant sites for biomass.

	B1	B2	B3	Total
Available biomass resource area (forest/agriculture land) (m^2)	571,089; 10,290,033	2,851,949; 5,801,903	1,266,171; 18,425,123	4,689,209; 34,517,059
Current land use	Mixed (agricultural land)	Forest, Agriculture land	Agriculture land	-
Annual heat production and electricity selling income	56,897 GJ; 379.3 M JPY	30,658 GJ; 204.5 M JPY	24,475 GJ; 163.1 M JPY	112,030 GJ; 746.9 M JPY
Distance from biomass resource area	1500–3000 m	1500–2000 m	500–3000 m	-
Distance to energy consumption area	500–3500 m	500–3000 m	500–2500 m	-
Access	Good	Good	Good	-
Land use regulation	Non-senbiki urban area [1]	Non-senbiki urban area	Outside urban planning area	-
Evacuation zone	No	No	Yes	-

[1] Non-senbiki urban area: area inside the urban planning area, but neither belonging to the urbanization promotion area, nor the urbanization control area in the Japanese land use planning system.

5.4. Scenario Analysis

In Scenario 1 (RE prioritized scenario), S1–S5 were selected as the five potential sites for mega-solar farms. Among which, S4 and S5 were located within the evacuation zones. W2, W3 and W9 were selected as potential sites for setting up 5 turbines, while 3 turbines were set within W9 in the evacuation zone. B2 and B3 were selected as the potential sites for biomass plants; while B3 was located in the evacuation zone. See Figure 11.

In Scenario 2 (evacuation zone prioritized scenario), S4 and S5 were selected as the potential sites for mega-solar farms. W9 and W10 were selected as the potential sites for setting up 8 wind turbines. B3 was selected as the potential site for setting up a biomass plant. See Figure 12.

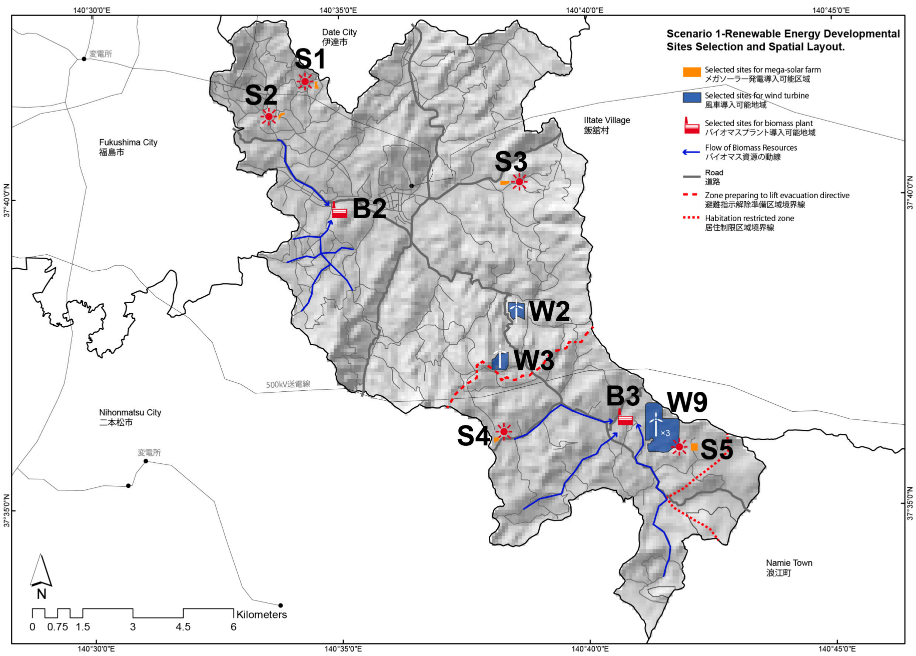

Figure 11. Scenario 1: renewable energy development site selection and spatial layout (source: the authors).

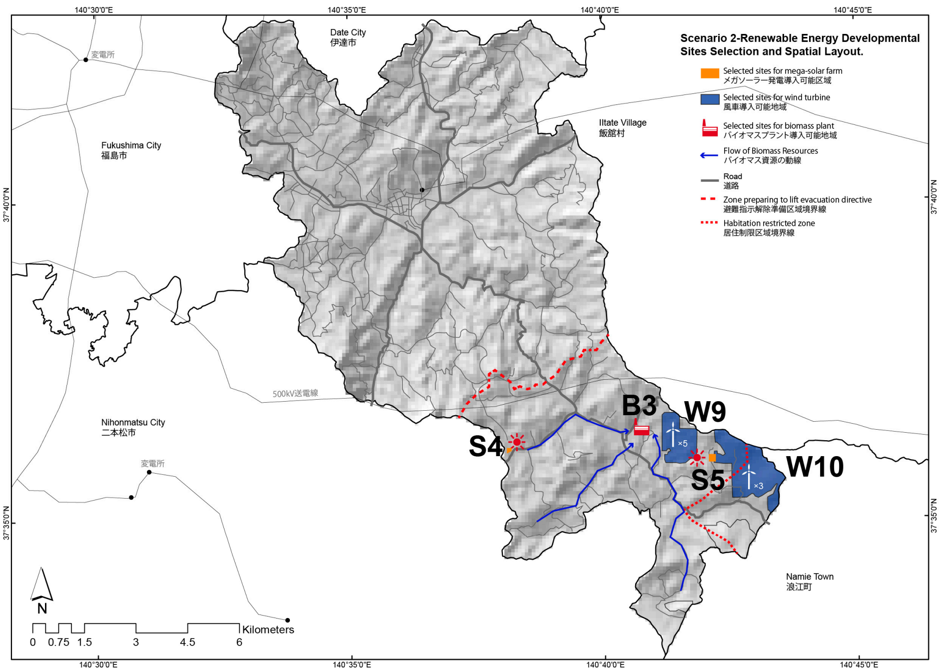

Figure 12. Scenario 2: renewable energy development site selection and spatial layout (source: the authors).

The results of the five evaluation criteria for Scenarios 1 and 2 are summarized in Table 6. Overall, Scenario 1 costs more and generates more energy than Scenario 2. It can thus supply more energy for houses and achieve a higher CO_2 reduction level. In Scenario 1, the proposed RE facilities are distributed in both southern (Yamakiya area, evacuation zones) and northern parts (old central area) within the town; thus they present a more balanced RE spatial strategy for the whole town. It can better strengthen the infrastructure improvement for the whole town, especially helping with infrastructure renewal for the old central area in Kawamata Town. In its planning and implementation, Scenario 1 may benefit more from the current infrastructure basis and potentials in the old central town. This can include industrial waste heat re-use and easy access to the current power line and substation. Furthermore, RE facilities located in the northern part of the town can provide clean energy for the new public houses that are close. The town could build "zero-energy" new public houses for evacuees as one of their sustainable approaches for post-earthquake revitalization.

Scenario 2 bears unique features, as well. It focused on developing the southern part of the town, which can improve infrastructure and provide more development opportunities for evacuation zones. If the abundant wind resources in the evacuation zones are exploited appropriately (i.e., developed as a wind park), the municipality may get benefits, such as: electricity production, income growth, jobs creation and local tourism boost, among others. However, the visual impact of big wind turbines should be carefully considered before exploitation. In the southern part of Kawamata Town, large agriculture areas have been contaminated, so it is difficult to develop traditional agriculture there. As an alternative way, cultivating economic plants, such as sugar cane and cassava, as biomass resources could be a good choice. This also provides a new way to revitalize local agriculture. It can include developing a plant factory (greenhouse cultivation) that can cultivate non-polluting organic vegetables for urban areas, in areas such as the Tokyo Metropolitan area. Based on the district energy system, biomass and wind power can provide heat and electricity for both old and new houses, as well as plant factories in the southern part of the town. Using clean energy may help with local sustainable lifestyle building. With regard to planning implementation, Scenario 2 has a high potential to develop a new town center in the south. Benefits from RE development, such as infrastructure improvement, job creation and green energy supply, may attract more people to return to their hometown, especially for those who live in the zone preparing for the lifting off of the evacuation directive in Yamakiya area.

Table 6. Results comparison between Scenarios 1 and 2 based on five criteria.

	Scenario	Construction Cost (JPY) [1]	Energy Production (MWh or GJ) and Income (JPY) [2]	Supply Number of Houses [3]	Viewshed: Visible Area (km^2)	CO_2 Reduction Amount (t) [4]
Solar	1	5100 M	17,870 MWh 571.9 M	3250	-	10,364.8
	2	2640 M	9251 MWh 296.0 M	1682	-	5365.3
Wind	1	3000 M	19,272 MWh 424.0 M	3504	3.94	11,177.8
	2	4800 M	30,835 MWh 678.4 M	5606	6.99	17,884.4
Biomass	1	717 M	55,133 GJ 367.6 M	2785	-	8883.2
	2	318 M	24,475 GJ 163.1 M	1236	-	3943.5
Total	1	8817 M	37,142 MWh; 55,133 GJ 1363.5 M	9539	3.94	30,425.8
	2	7758 M	40,086 MWh; 24,475 GJ 1137.5 M	8524	6.99	27,193.2

[1] Mega-solar 300,000 JPY/kW; wind turbine 300,000 JPY/kW; biomass-electricity 410,000 JPY/kW. [2] Electricity production per year = RE facility capacity × hours (8760) × energy efficiency factor (solar 12%; wind 22%-estimated based on national average efficiency factor during 2003–2011 in Japan [28]; biomass electricity 20%). The 2014 Japanese FIT price, mega-solar, 32 JPY/kWh; wind, 22 JPY/kWh; biomass-electricity/heat, 24 JPY/kWh. [3] Average electricity consumption per family: about 5500 kWh. [4] CO_2 reducing factor: 0.58 kg/kWh [29].

6. Conclusions and Recommendations

The results show that GIS is an efficient tool to provide quantified and visual information on local RE potentials and its developmental alternatives at the municipal level. In Kawamata Town, the total potential capacity for mega-solar, wind turbines and biomass reached 17 MW, 56 MW and 112,030 GJ, respectively. Exploiting the above potential to the maximum limitation can bring 3943.7 M JPY in income to the town in a year. Besides, theme maps and quantified data generated through the proposed approach can be used in the local RE planning process. It can also guide the action plan for sustainable energy [30], enhance the interactive dialogue and the feasibility of local participation within the municipality. This would facilitate a transition of the municipal energy structure towards a more sustainable level. RE promotion can contribute to local sustainable development and post-earthquake revitalization, through job creation [31], environmental education [32], CO_2 emission reduction [8,10,33] and agricultural revitalization [32], among others.

After the Great North Eastern Japan Earthquake (2011), Kawamata Town set the principles for their future development, keynotes, such as 3R (reduce, reuse, recycle), zero nuclear power, greenhouse effect mitigation and the security of the energy supply in harmony with nature, were proposed [34]. As the results of scenario analysis indicated, RE can provide safe power for about 9000 households and reduce CO_2 emission at about 29,000 t per year. Specifically, in regard to how to integrate the energy planning with local post-earthquake revitalization, RE plans can serve as one of the significant subordinate plans for "The Revitalization Plan of Kawamata Town" [34]. The proposed approach can facilitate local RE plan making and help to build its post-earthquake energy vision. In this plan, three main goals for post-earthquake revitalization were set: safety, job creation and bonds. Based on the above goals, several action strategies were proposed. They include: to build a disaster-resistant town, to promote RE, to revive local business and industry and to foster strong children for the future among others. It is not hard to find out that RE promotion has been considered as one of the main approaches for local revitalization. The RE planning can support Kawamata's "Depopulation Smart Community Project" with clean energy supply for public facilities, houses and vehicles in the community.

The results also show that exploitable solar, wind and biomass potentials exist in Kawamata Town, Japan. Within the evacuation zones, wind power resources are abundant. However, the visual impact of large-sized wind turbines should have attention paid to it. Biomass resources should be carefully monitored due to local radiation issues. Prioritized promotion of RE in the evacuation zones may help with job creation and infrastructure improvement, thus attracting more people to return to the town. In addition to the suggestions for local RE promotion, we give further recommendations that may be combined with RE promotion as integrated strategies for local sustainable development and post-earthquake revitalization as follows:

- Energy saving and waste energy re-use approaches: strengthen energy saving, re-use industrial waste heat for building/district heating, among others.
- Housing development: possibilities to build new public houses (for evacuees) and guest houses as zero-energy houses.
- District heating network: to consider developing a district heating system for new public houses, new residential areas in the evacuation zone and the old central town area powered by biomass resources.
- Agriculture survival: to import "plant factories" (indoor greenhouse vegetable cultivation technology) to respond to vegetation safety issues due to radiation. Artificial lighting energy in the greenhouses can be provided by PV panels or wind turbines.
- Local tourism: establish a wind park/RE park to cater to local tourism and provide environmental education opportunities.
- Local citizens' participation: citizens to invest in wind turbines, mega-solar farms or in the local RE company established and managed by the local people.

Based on the study results and the above recommendations, we proposed an RE master plan for Kawamata Town; see Figure 13.

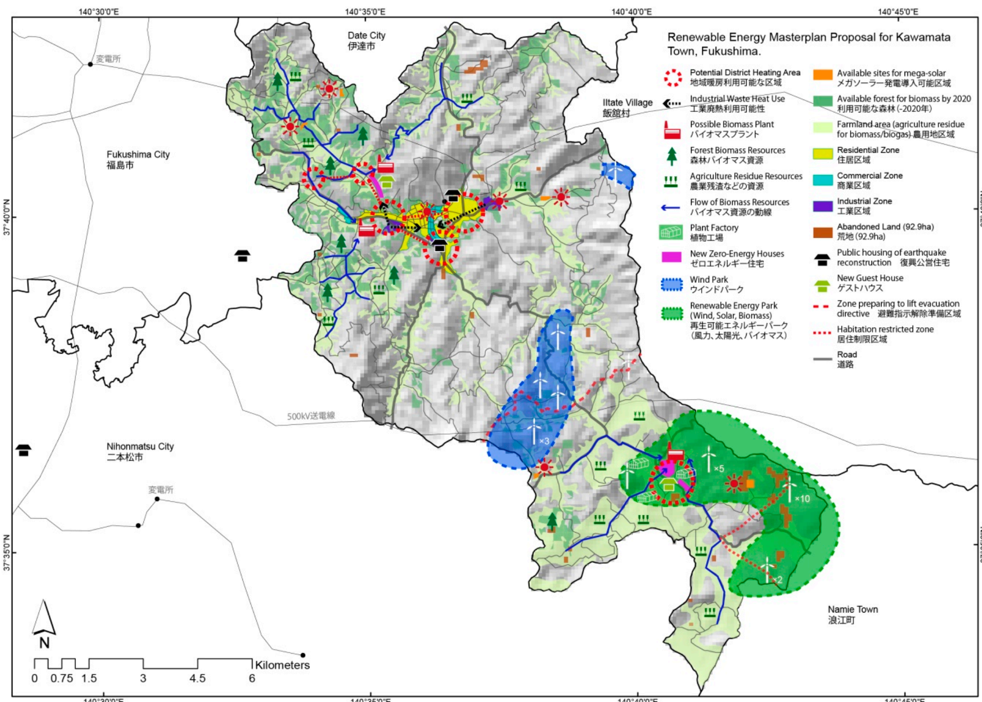

Figure 13. Renewable energy master plan proposal for Kawamata Town (source: the authors).

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Author Contributions: Qianna Wang, Martin Mwirigi M'Ikiugu and Isami Kinoshita conceived of the study. Qianna Wang conducted the site survey, data collection, data analysis and wrote the paper. Martin Mwirigi M'Ikiugu contributed to data analysis, result discussion and paper revision. Yanyun Luo helped with paper writing and revision. Isami Kinoshita supervised the study, introduced the case study site and helped with the site survey and paper revision.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

GIS	Geographic Information System
RE	Renewable Energy
RES	Renewable Energy Resource
FIT	Feed-in Tariff
NEDO	New Energy and Industrial Technology Development Organization
PV	Photovoltaic
JPY	Japanese Yen
GJ	Giga Joule
MJ	Mega Joule
MW	Megawatt
kW	Kilowatt
MWh	Megawatt hour
kWh	Kilowatt hour
mSv	Millisievert
µSv	Microsievert

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