Sustainability **2014**, *6*, 2087-2117; doi:10.3390/su6042087

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

A GIS-Based Approach in Support of Spatial Planning for Renewable Energy: A Case Study of Fukushima, Japan

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Received: 27 February 2014; in revised form: 1 April 2014 / Accepted: 2 April 2014 / Published: 14 April 2014

Abstract: This paper presents an approach in support of spatial planning for renewable energy at the regional level. It aims to establish an elaborate and informative procedure, as well as integrated quantification and visualization, to support decision making. The proposed approach is composed of a set of sequential steps that include primary energy consumption estimation, renewable energy potential estimation, energy self-sufficiency analysis, and composite map preparation using Geographic Information System (GIS). GIS is used to analyze solar, wind, biomass, geothermal, and hydro-power potential within Fukushima Prefecture, Japan. Potential sites are determined based on geographic, topographic, and land use constraints. Evacuees' population and forest radiation levels are specifically considered in the context of consequent issues emanating from Fukushima Daiichi nuclear crisis. Energy self-sufficiency analysis has been conducted for years 2020 and 2030. A composite map showing potential sites and their interrelation to the above renewable energy resources has also been presented. These results may support decision making in regional renewable energy planning, by providing information on regional potentials and restrictions to different energy stakeholders. This can help to build an energy developmental vision, which can drive regional energy development towards sustainability. The proposed approach can also be applied to other Japanese municipalities or regions. It provides an example on how to establish local GIS databases through the utilization of various online open GIS resources in Japan.

Keywords: spatial planning; renewable energy; sustainability; GIS; Fukushima prefecture

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1. Introduction

Renewable Energy (RE) is receiving increasing attention for its clean, green, and safe characteristics. It drives the energy structure towards a sustainable level by providing a sustainable approach to energy generation [1,2], and contributing to mitigation of the greenhouse effect in the long term [3]. It also plays a vital role in the overall sustainable development strategy [3,4]. The spatial distribution of Renewable Energy Sources (RES) is strongly affected by geographic and topographic factors such as altitude, climate, and terrain conditions [5]. Thus, exploration and supply of RE take place at the local or regional levels [6,7]. These features also shape RE supply networks to be distributed in decentralized forms, that consequently make the planning of RE concentrated on a detailed scale.

Geographic Information Systems (GIS) have proved to be a useful tool for regional RE potential estimation [8–10] and support for decision making in energy planning [7,11,12]. This is due to their flexible data management and spatial-temporal analysis capability. Furthermore, the visualization function of GIS can connect statistical analysis with visualized spatial data in the integrated RE planning approach. Such visualization maps may make it easy to understand planning for policy makers, private investors, and citizens. It also provides a platform for information sharing and planning participation through Web-based GIS [13,14].

At the regional level, several traditional techniques have been applied in RE planning. These include Multiple-Criteria Decision Analysis (MCDA) [15–20], Delphi surveys [21–23], and participatory approach [24]. There are also a few methodologies and empirical studies on RE planning in literature. Terrados *et al.* [20] proposed a combined methodology for RE planning; a hybrid composed of SWOT analysis, MCDA, and Delphi methods. Sarafidis *et al.* [6] established a planning approach for RE that compared energy demand estimation and RES potential estimation to identify the most effective exploitation of RES in the study regions. Droege [25] introduced a framework and several tools to help in building a renewable energy system at the city scale. In planning practice, an aim to achieve 100% energy self-sufficiency through RE supply has been a common trend among European municipalities. Some of them such as Mauenheim (Germany) and Gussing (Austria) have achieved or will achieve energy autonomy in the coming decade [26]. Nevertheless, RE planning application has often been limited to district [27], community, or city scale [28]. Previous research has focused on estimation [7–10,29] and mapping [30] of RES, whereas energy self-sufficiency analysis based on demand-supply prediction at the regional level has been lacking.

The Japanese Government issued its new "Basic Energy Plan" in June, 2010. One of its five main targets was a proposal to increase the proportion of zero emission electricity power (nuclear power and RE) to 70% of the total electricity generation by 2030 [31]. To achieve this target, RE was to be increased from 8%–9%, and nuclear power from 26%–50%. However, the Great North Eastern Japan Earthquake on March 11, 2011, and the consequent Fukushima Daiichi nuclear crisis evoked great concerns on the safety of nuclear power worldwide. Accordingly, this has led to difficulties in further promotion of nuclear power, in Japan. In this context, the Feed-in Tariff (FIT) of RE was announced and started in July, 2012, and is expected to accelerate the RE's development in Japan. As Fukushima is the prefecture most affected by the nuclear crisis, its government has realized the urgent need to develop clean, green, and safe RE to drive its energy structure into a safer and more self-sufficient status. Renewable energy, therefore, may play an important role in the post-earthquake reconstruction and economic growth in Fukushima prefecture in the coming decades.

This study proposed a GIS-based integrated approach to estimate energy self-sufficiency possibility at the regional level, based on primary energy consumption and available RE potential estimation. It aimed to establish an elaborate and informative procedure, as well as integrated quantification and visualization to support decision-making in RE spatial planning. The proposed approach is composed of a set of sequential steps that include; primary energy consumption estimation, renewable energy potential estimation, energy self-sufficiency analysis, and composite map preparation using GIS. This approach takes a step further from previous works that only dealt with GIS-based RE potential estimation or site selection. It takes into account the future of energy self-sufficiency possibilities, and multiple RES potential sites analysis at the regional level using GIS. We have also suggested the integration of spatial planning concepts into this approach, and put emphasis on several guidelines which should be considered in the RE spatial planning process. We applied this approach in Fukushima Prefecture, Japan, because of the planning needs to support the prefectural future RE developmental vision for 2020 and 2030. The proposed approach may help with decision-making in support of the RE planning process. This is through the provision of quantification and visualization of information on regional potentials and restrictions, to different energy stakeholders such as the energy policy makers and local authorities. Moreover, the approach presented in this study can serve as an example applicable in other Japanese municipalities to help in building a safer and sustainable energy system.

2. Planning for Renewable Energy: A Chance for Spatial Planning?

Spatial planning is considered as a complex system for organizing the development of physical space, aiming to mediate the relationship between spatial development and social, economic, as well as ecological requirements [32]. It usually embraces land use planning and relevant public policy. In one of the earliest description of spatial planning, European Conference of Ministers responsible for Regional Planning (CEMAT) stated the following. Spatial planning gives "geographic expression to the economic, social, cultural, and ecological policies of the society". It is "a scientific discipline, an administrative technique, and a policy developed as an interdisciplinary and comprehensive approach directed towards balancing regional development and the physical organization of space according to an overall strategy" (The European regional/spatial planning charter adopted in 1983) [33].

Healey [34] pointed out that spatial planning systems varied due to different styles of administration and government, as well as their consequent policy tools, institutional arrangements and their personnel. Commission of the European Communities [35] described spatial planning as the method used largely by the public sector to influence the future distribution of activities in space. It is undertaken with the aim of creating a more rational territorial organization of land uses and the linkages between them. This includes the aim to balance demands for development with the need to protect the environment, and to achieve social and economic objectives. Kinoshita [36] argued that spatial planning should help in implementing long term, economical, and harmonious use of space between human beings and the physical environment. Koresawa and Konvitz [37] indicated that spatial planning identifies long and medium term objectives and strategies for territories, dealing with land use and development as a government activity. They also stated that it coordinates sectoral policies such as transport, agriculture, and environment. Furthermore, Alden *et al.* [38] stated that spatial planning is a concept wider than land-use planning. The main features of spatial planning are its close relationship with land-use and physical planning, as well as social, environmental, and policy development. Its other features include resource and investment distribution, collaboration with the public and citizens, and proper evaluation.

Although there is no universally accepted definition of spatial planning, we can identify some characteristics from the above descriptions. (1) Spatial planning works closely with land use planning, but spatial planning concept is wider than land use planning; This is because (2) spatial planning integrates with comprehensive approaches that meet social, economic, and ecological requirements; (3) Spatial planning's long term objective is to organize physical spaces for harmony between human beings and the environment, and create sustainable spatial development; (4) Spatial planning represents different administration and government styles, and often involves public and citizen participation in the spatial planning process.

European Union (EU) member states adopted the European Spatial Development Perspective (ESDP) in 1999. ESDP provided the essential instruments for trans-national and cross border co-operation for spatial planning in Europe. In 2007, the Territorial Agenda of the EU was adopted to supplement ESDP. It improved the integrated spatial policy for the EU member states. According to Kinoshita [39], impacts from political intervention and existing policies such as the agricultural land conversion policy, results in a weak binding force of land use planning in Japan, making it vulnerable. Furthermore, conservation plans for natural resources, such as landscape planning that comprehensively focus on land use, bio-diversity, history, and culture have not been integrated into the Japanese land use planning system. Because Japanese Landscape Law was only legislated in 2004, it may take a long time to integrate the landscape view of point into land use planning. Therefore, a comprehensive spatial planning system has not been established in Japan yet.

Japanese rural areas are now facing aging and depopulation problems because young people tend to gravitate towards urban areas. This brings more population pressure and land scarcity to urban areas. Under the concept of sustainable development, new approaches to redesign and restructure urban areas have been undertaken at all spatial scales from the regional, city, community to the building levels; in areas such as passive solar design [40]. There is high energy demand and consumption in urban areas, but it is difficult to install large scale RE facilities in these areas due to land limitations. In contrast, rural areas have a high potential of available land and agricultural residues, which provide more possibilities for RE development. Jobs created by local RE development [41,42] can help to bring a young populations back to rural areas. Electricity sales can increase local income, and enhance local energy self-sufficiency that can keep capital in local areas [26]. To improve energy self-sufficiency at the regional scale, the key point should be to address the energy demand-supply mismatch between urban and rural areas. Thus, consciousness in planning for energy demand and supply between urban and rural areas is important at the regional scale. According to Gret-Regamey and Crespo [43], spatial planning role in urban and rural planning is that it seeks to regulate demand for land resources with a view to securing the well-being of urban and rural communities. Unlike general energy or urban planning, spatial planning aims to organize future activities distribution in the physical environment. It mainly deals with the relationship between physical land uses, social, economic, and the environmental requirements for the future society. We argue that some basic concepts of spatial planning, such as spatial organization for future sustainable development, consideration for balancing spatial development with social, economic, and ecological requirements are applicable in the RE planning field too. The full introduction of GIS-based approach in support of spatial planning for RE has not been well utilized until now, mainly due to lack of multidisciplinary knowledge and know-how between spatial planning and energy planning fields.

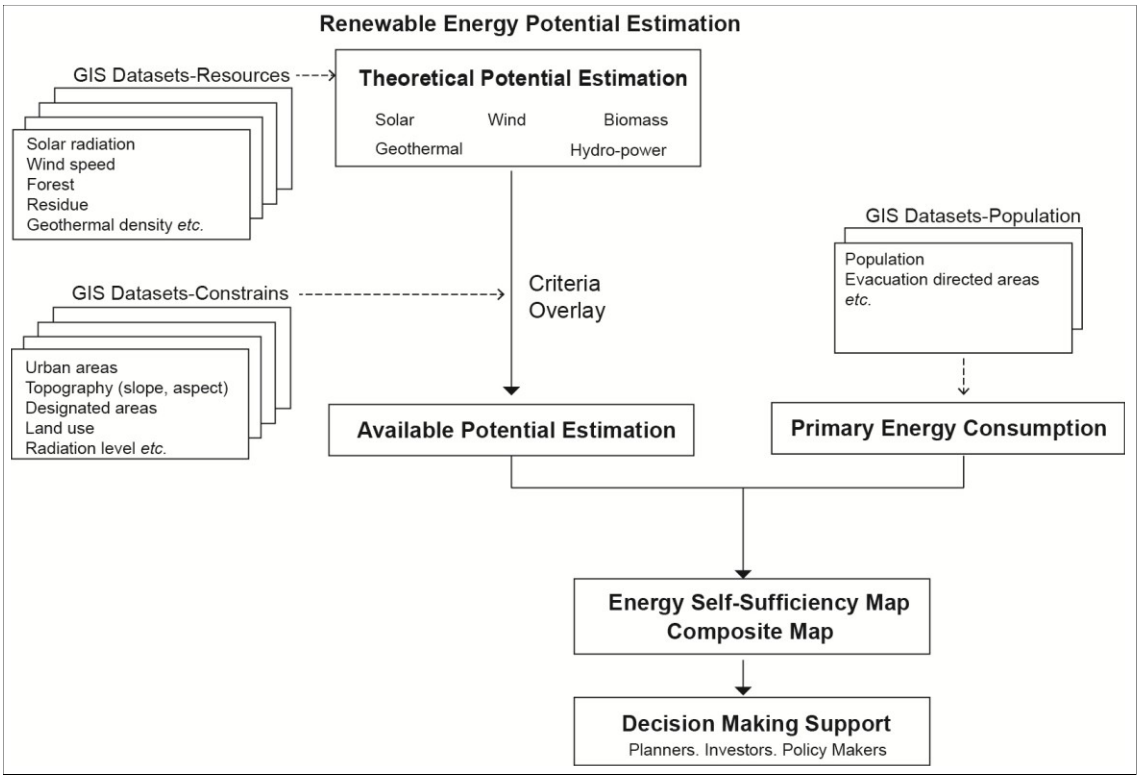
3. Proposal for a New Spatial Planning Approach for Renewable Energy

In this context, we proposed an approach to elaborate integrated information for decision-making in support of RE spatial planning at the regional level, taking into account the possibilities for future energy self-sufficiency. The proposed approach is composed of five main steps:

(1) Primary energy consumption analysis.
(2) RE potential estimation: theoretical potential estimation and available potential estimation.
(3) Energy self-sufficiency analysis.
(4) Composite map preparation.
(5) Decision making support in RE planning.

The procedure to implement the proposed approach is described step by step from Sections 5.1–5.5. Figure 1 shows the illustration of the approach framework.

Figure 1. Proposed approach framework.



4. Study Area

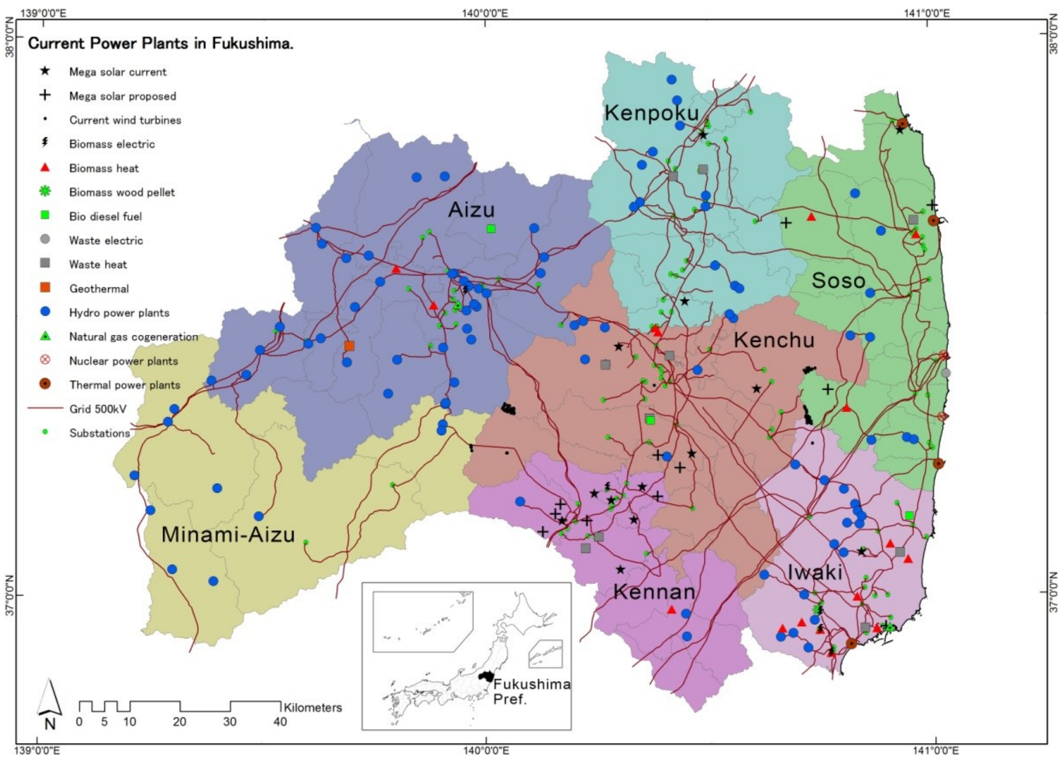
Fukushima prefecture is located in the northeastern region of Japan, about 200 km north of Tokyo. It covers an area of 13,782 km^2, with a population of 1,946,526 (2013). The prefecture is divided into three main regions. From west-east order, they are (1) Aizu region that includes Aizu and Minami Aizu areas; (2) Naka-doori region that includes Kenpoku, Kenchu, and Kennan areas; and (3) Hama-doori that includes Soso and Iwaki areas. Aizu region has hilly topography and is mostly forested. Naka-doori and Hama-doori have a flatter topography, with most of the population and built-up areas distributed in these regions. Both densely populated urban areas and depopulated rural areas coexist in the prefecture.

Fukushima Prefecture was heavily damaged by the Great North Eastern Japan earthquake of March 11, 2011, and the consequent Fukushima Daiichi nuclear crisis. Large areas of Fukushima have been contaminated by radioactive particles. Areas with high radiation levels have been designated as evacuation directed areas, such as Futaba and Namie towns. There were about 150,000 people evacuated inside or outside of Fukushima prefecture after the earthquake and nuclear crisis.

In order to develop a safer and environmental-friendly energy supply system, Fukushima Government is currently putting efforts in RE promotion. This has been considered as one of the approaches to support post-earthquake reconstruction. From 2009–2020, the government has proposed the increase of total solar panel capacity from 38.9–1000 MW, wind turbine capacity from 69.9–2000 MW, hydro-power plant capacity from 3973.5–3980 MW, biomass electricity capacity from 66.4–360 MW, and geothermal plant capacity from 65–67 MW [44].

Fukushima now has several types of RE facilities. They include wind turbines, solar PV (household and mega-solar), solar heating, biomass (electricity and heat), hydro-power, geothermal, bio fuel, and natural gas co-generation. There existed no complete GIS data for all the RE facilities in Fukushima, hence we gathered their details (capacity, year among others) from different resources. They included wind [45], solar PV mega-solar [46–48], biomass [49], hydro-power [47,49], geothermal [49], biofuel [49], and natural gas co-generation [49]). Then we created point data for current RE facilities in GIS. We also derived a grid and substation map based on information from online RE potential database provided by Fukushima Government [49]. Figure 2 illustrates different regions, as well as power plants and grid in Fukushima prefecture.

Figure 2. Regions, power plants, and grid network in Fukushima.



5. Case Study: Methods, Datasets

5.1. Primary Energy Consumption

In the energy planning process, energy consumption analysis is fundamental. Energy consumption is usually summarized in two forms; primary energy consumption, and final energy consumption. We chose to analyze primary energy consumption because of complexity and data scarcity for final energy consumption calculations. The primary energy consumption (GJ/year) was multiplied by primary energy consumption per person (GJ/per person) by population, see Table 1.

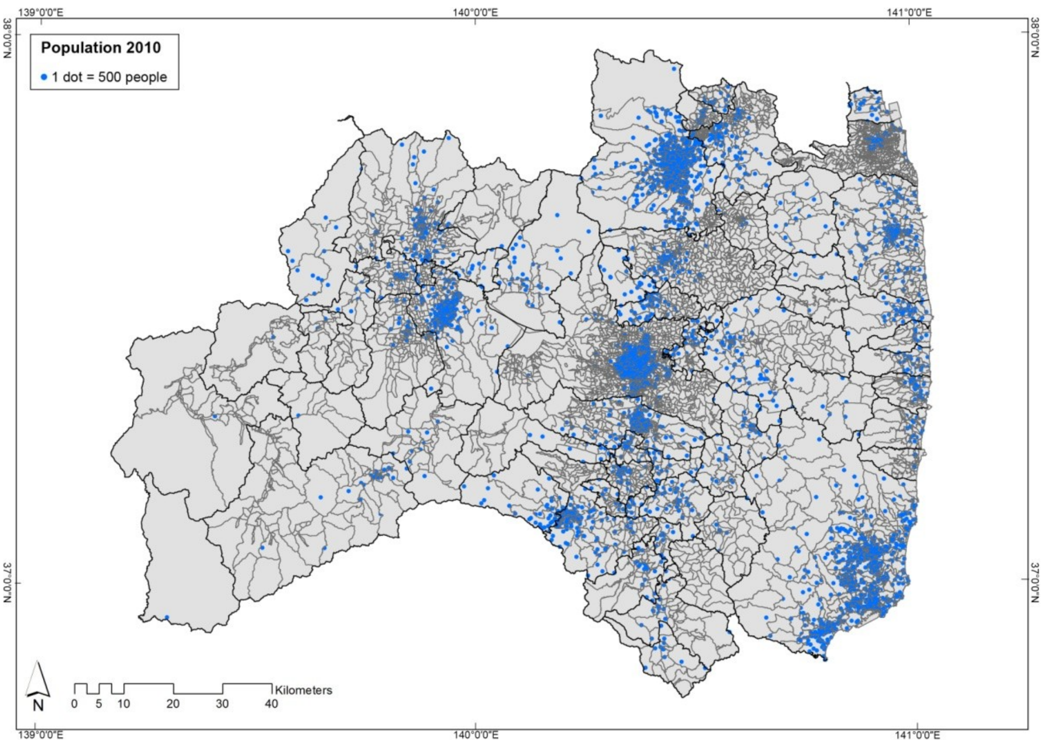
Table 1. Japan Primary Energy Consumption and Population in 2010, 2020, and 2030.

Japan	2010	2020	2030
Total Primary Energy Consumption [50]	501 Mtoe [(1)]	491 Mtoe	482 Mtoe
Total Population [51]	128,060,000	124,100,000	116,620,000
Primary Energy Consumption/person	3.9 toe/person	3.96 toe/person	4.13 toe/person

[(1)] toe: tonne of oil equivalent. 1 toe ≈ 41.87 GJ.

We obtained GIS population data (2010) for Fukushima from Japan Government Statistics [52]. The population data is contained in sub-municipal (small regions that constitute one municipality) level, see Figure 3. We downloaded the original data for each municipality in Fukushima, and then merged all the municipalities' data into one Fukushima prefectural population data using ArcGIS 10.1 (herein referred to as GIS).

Figure 3. Fukushima population (2010) presented by dot density.



The above population data was for year 2010, but there was a lot of population movement in Fukushima due to the great earthquake of 2011. To gain a more accurate future population prediction, we calculated the population by the end of 2011, which formed population prediction basis. Two main population movements were considered: voluntary evacuees' population outside evacuation directed zones, and the population inside evacuation directed zones. By September 2011, there were 50,327 people, who had voluntary evacuation from un-evacuation directed zones. Of them, 23,551 had evacuated within Fukushima, and 26,776 outside of Fukushima. There were 100,510 people from evacuation directed zones; 70,817 of them evacuated within Fukushima while 29,693 evacuated outside Fukushima [53]. We corrected population data for 2011 as follows. For the population of voluntary evacuation from un-evacuation directed zones, we subtracted the number of people evacuated outside Fukushima (total 26,776) based on each municipality's voluntary evacuation number [53]. For the population from inside the evacuation directed zone, we first edited the population to zero (0) in GIS. Then, we added the number of people evacuated within Fukushima (total 70,817) to un-evacuation directed zones based on each municipality's evacuation entrants [53]. The evacuation directed zone is bound to change in the future. In October 2013, Japanese Ministry of Land, Infrastructure, Transport, and Tourism revised the boundary of evacuated zones and classified it into three categories. (1) Difficult to return zone (>50 mSv/year, 5 years later, air dose rate will still be >20 mSV/year); (2) Habitation restriction zone (>20 mSv/year, after planned decontamination, aiming to rebuild the community several years later); (3) Zone preparing for lifting off the evacuation directive (<20 mSv/year, aim to recover as soon as possible for restoration and reconstruction, residents expected to return) [54]. In this study, for the difficult to return zone, we assumed that 0% of the residents will return by 2020 [54] and that 20% of the residents will return by 2030. For the habitation restriction zone, we assumed that 40% of residents will return by 2020, and 60% by 2030. For zone preparing to lift the evacuation directive, we assumed 60% of the residents will return by 2020, and 80% by 2030 [55].

After the above corrections, we estimated the population for Fukushima by years 2020 and 2030. Population in Fukushima will decrease by about 7.52% by 2020 compared to year 2010, and by about 16.99% by 2030 compared to that of year 2010 [51]. We calculated Fukushima's population by 2020 and 2030 based on the above rates of decrease. Then we calculated the primary energy consumption based on this population prediction. We consequently converted the results into 500 m mesh data using GIS as follows. We first calculated population density for municipalities using the Field Calculator in GIS. Secondly, we did a spatial join of the population density and the Japanese standard 500 m mesh (as the background layer). Then, we calculated the population in all 500 m meshes by multiplying population density with area using the Field Calculator.

In this study, we used Japanese Mesh System that has uniform geographic position and specific mesh ID [56]. In this way, we ensured uniformity of mesh position for further GIS analysis. The mesh system is in five mesh levels [57]. They are: (1) Primary region partition mesh (Longitude interval: 1°; Latitude interval: 40′) that has approximately 80 km × 80 km squares; (2) Second region partition mesh (Longitude interval: 7′30″; Latitude interval: 5′) that has approximately 10 km × 10 km squares. (3) Standard region partition mesh (Longitude interval: 45″; Latitude interval: 30′) that has approximately 1 km × 1 km squares, herein referred to as Japanese standard 1 km mesh; (4) Half of standard region partition mesh (Longitude interval: 22.5″; Latitude interval: 15′) that has approximately 500 m × 500 m squares, herein referred to as Japanese standard 500 m mesh. (5) Quarter of standard region partition mesh (Longitude interval: 11.25″; Latitude interval: 7.5′) that has approximately 250 m × 250 m squares.

5.2. Estimation of Renewable Energy Potential

At the regional level, types of RES vary due to different environmental conditions. In this study, we focused specifically on wind, solar, biomass, geothermal, and hydro-power because they are the five main renewable resources in Fukushima. At first, their theoretical potential was analyzed, and then the available potential. Theoretical potential is defined as the maximum potential of a RES in a region, with no environmental or social constraints considered [7]. Available potential is defined as harvestable RE potential after considering technical, environmental, and socio-economic constraints. It forms part of theoretical potential. The estimation methods for theoretical and available potentials are explained as follows.

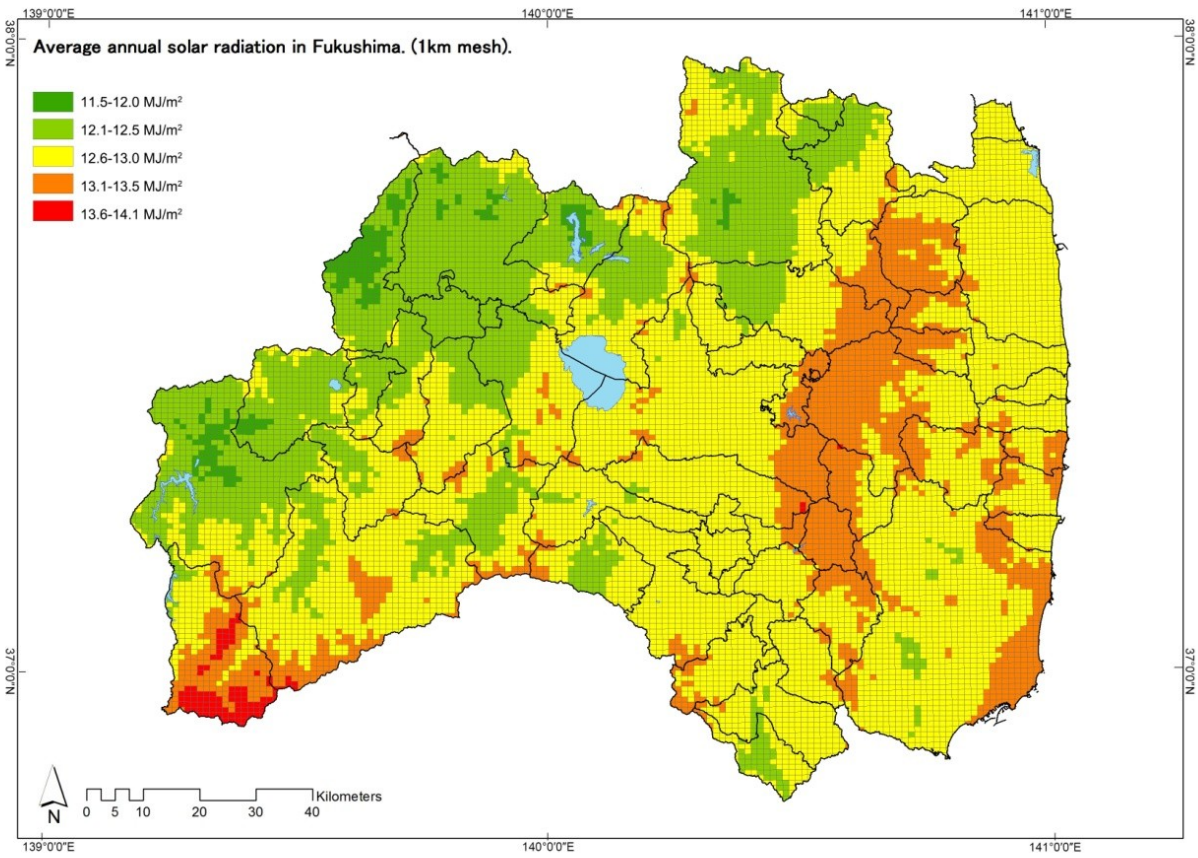
5.2.1. Solar Photovoltaic

The estimation for the solar potential was calculated based on climate data(polygon, 1 km mesh) which includes information on average annual solar radiation (per day) provided by Japanese Ministry of Land, Infrastructure, Transport and Tourism [58], see Figure 4. We calculated the solar potential within a new field using the Field Calculator as follows [59]:

$$S_t = S_1 \times 365 \times S_2 \times \eta \quad (1)$$

where S_t is solar potential in MJ/year, S_1 is the average annual solar radiation per day in MJ/m^2, 365 is the total days for one year, S_2 is the geographic area in m^2, η is the energy efficiency factor of solar Photovoltaic (PV) panel, and we set η as 12% [60].

Figure 4. Average annual solar radiation in Fukushima (1 km mesh).



The exploitation of available solar resources was done only for Mega-solar (over 1 MW) farm installations in this planning approach because general household PV panels can be installed on any rooftop in Fukushima. For mega-solar farm, available sites were selected based on the following criteria:

- Non-urbanized areas or industrial areas in urbanized areas.
- Slope: 0%–2.5%, any aspect; 2.5%–15%, south-facing aspect [9].
- Exclude superior agricultural areas, protected forest areas, natural preservation areas, national parks (special preservation area), and landslide areas assigned by relative laws in Japan [61].
- Un-available land use: rice fields, built-up areas, roads, railways, rivers and lakes, beaches, golf courses, and others (airports, artificial landfill areas among others). Available land uses: other agricultural areas (fruit orchards among others), forests, and barren lands [61].
- Minimum available land area of 1.5 ha [46].

A summary of GIS data resources we used for solar potential estimation is as follows. Fukushima municipal boundary (polyline, 1:25,000) obtained from Geospatial Information Authority of Japan [62]. Climate (polygon, 1 km mesh), topography (polygon, 500 m mesh), and designated area (polygon, 1:50,000). Land use 2009 (polygon, 100 m mesh) data obtained from the national land numerical information download service provided by Japanese Ministry of Land, Infrastructure, Transport and Tourism [58].

5.2.2. Wind Energy

We only found 500 m mesh wind speed data (at the height of 70 m, with geographic coordinates) in ".dat" format [63]. Therefore, we first created fishnet based on Japanese standard 500 m mesh. Then, we opened ".dat" data using Microsoft Excel 2010 and coded all the wind speed data according to the ID of each mesh in fishnet, respectively. Finally, we converted it into ".dbf" format using Microsoft Access 2010 and updated the original fishnet ".dbf" data by replacing it with the new one, see Figure 5. Currently, there are 80 wind turbines in Fukushima with 70 of them having a capacity of 2000 kW and 90 m in blade diameter that we have used for estimation in this study. The potential of wind power was calculated within a new field using the Field Calculator as follows [64]:

$$\mathrm{Q} = \mathrm{F} \times \sum Fi(Vi) \times 8760 \times Pi \tag{2}$$

where Q is the wind potential in kWh/year, F is the total number of wind turbines that can be possibly set. $Fi(Vi)$ is the annual occurrence frequency of wind speed (i), 8760 is the total number of hours in one year, and Pi is one wind turbine's output in kW under different wind speeds following its output curve.

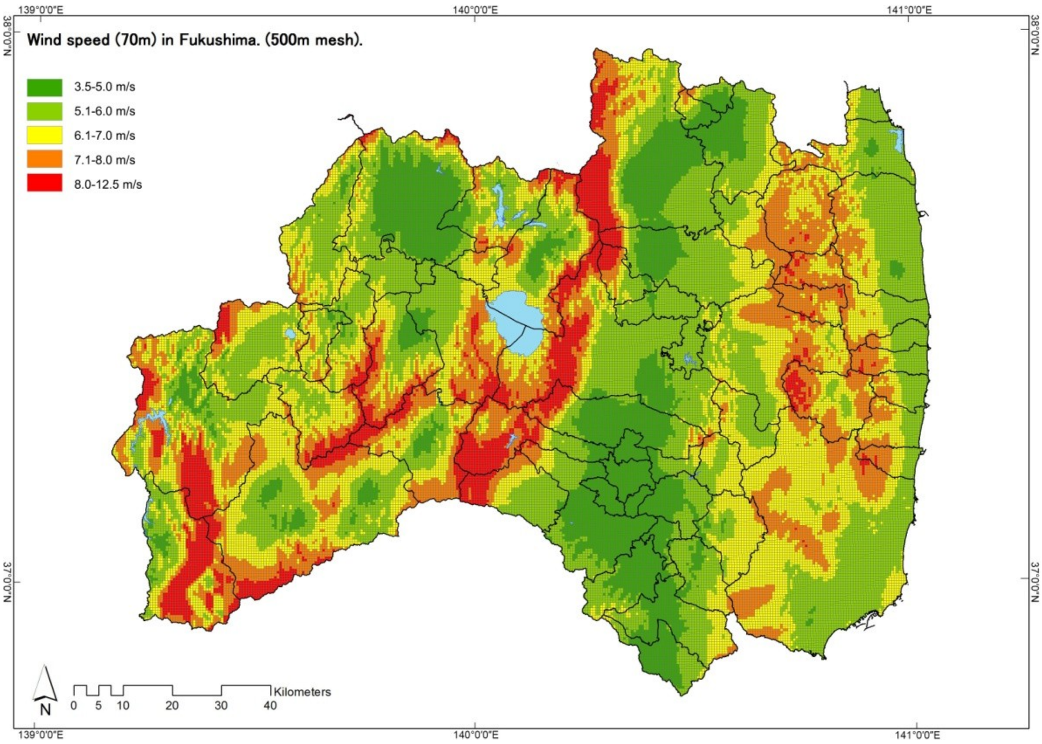
Wind turbines, especially the big ones (>1000 kW) are usually set at a distance of 10 times blade diameters (10 D) apart based on wind flow and turbine efficiency consideration. Thus, one wind turbine at least takes about an area of $(10\ \mathrm{D})^2$. F can be calculated by the total geographic area divided by $(10\ \mathrm{D})^2$.

For the available wind potential, the criteria to select suitable sites are proposed as follows:

- Wind speed > 6.0 m/s at the height of 70 m [6,7].
- Altitude < 1000 m [6–7,10,61].
- Slope < 20° [61].
- Non-urbanization area [61].

- Exclude superior agricultural areas, protected forest areas, natural preservation areas, national parks (special preservation areas), landslide areas, and wildlife conservation areas assigned by relative laws in Japan [61].
- Buffer distances: cities and towns > 2000 m [65], villages > 500 m [61,65,66], water bodies and wetlands > 500 m [9], ecological sensitive areas > 1000 m [9,65], airports > 2500 m [7], historical areas > 2000 m [7,65,66].
- Unavailable land uses: rice fields, built-up areas, roads, railways, rivers and lakes, golf courses, and others (airports, artificial landfill areas among others). Available land uses: other agricultural areas (fruit orchards among others), forests, barren lands, and beaches [61].

Figure 5. Wind speed in Fukushima (500 m mesh, at the height of 70 m).



GIS resources used were Fukushima municipal boundary, topography, designated areas, and land use datasets, the same we used for solar potential estimation in Section 5.2.1. Wind speed data (in the form of ".dat" files, converted to GIS mesh polygon as mentioned above) and their annual occurrence frequency (bar graph) were obtained from the local area wind energy prediction system provided by New Energy and Industrial Technology Development Organization (NEDO) [63].

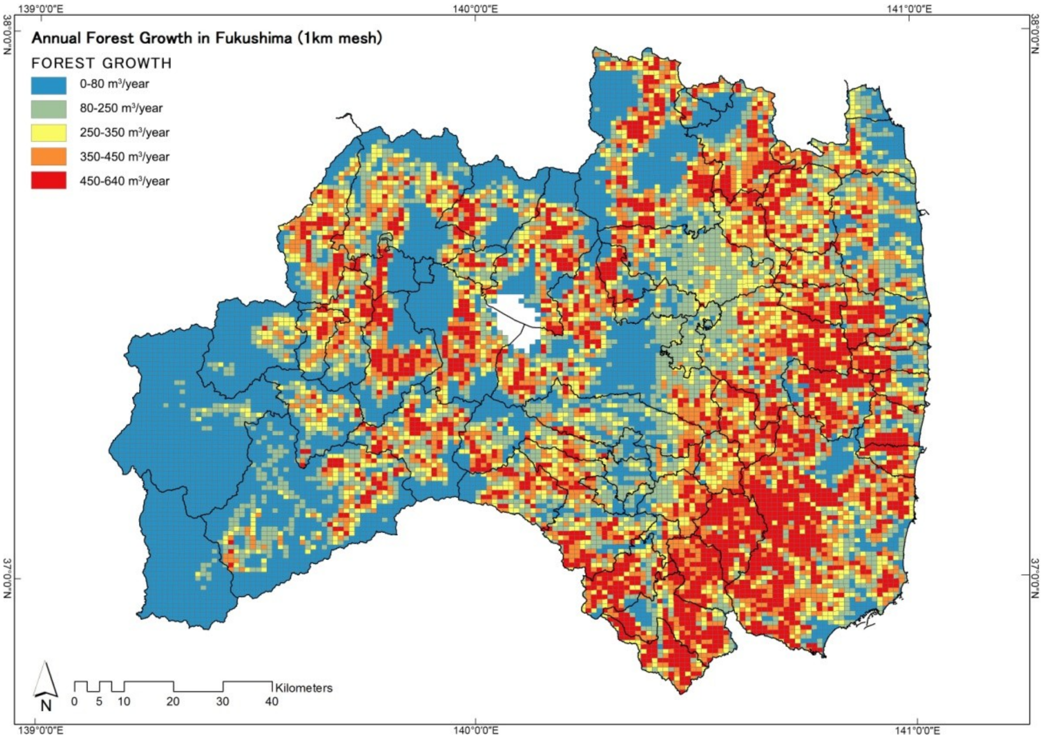
5.2.3. Biomass

Biomass resources were classified into two categories: wood biomass and residue biomass (agricultural residues and animal waste among others). For wood biomass estimation, we used the dataset created by NEDO [67], which include annual forest growth data in Japanese standard 1 km mesh, see Figure 6. Then, we estimated the potential of wood biomass within a new field using the Field Calculator based on the following equation [59]:

$$Q = S \times 500 \times C \times \eta \quad (3)$$

where Q is the wood biomass potential in MJ/year, S is the annual forest growth in m^3/year, and 500 is the wood weight unit in kg/m^3. C is the calorific unit in MJ/kg (needle leaf trees 19.78MJ/kg, broadleaf trees 18.80 mJ/kg), and η is the energy efficiency factor for biomass co-generation boiler. We set η as 80% [60].

Figure 6. Annual forest growth rate in Fukushima (1 km mesh).



To select the available forest, we proposed the following criteria.

- Forest area.
- Exclude protected forest areas, natural preservation areas, national parks (special preservation areas), and wildlife conservation areas assigned by relative laws in Japan.
- Slope < 20% [5,10].

Besides, Fukushima has a special problem of radiation in its forests. Forests in Fukushima have been strongly affected by radioactive material, Cesium (Cs). Only parts of the forests are safe to be incinerated in boilers. With the passage of time, radioactive materials will physically decay. Thus, we need to estimate available wood biomass potential based on the forests under certain radiation levels in the future.

According to a report by Fukushima prefecture, the usable wood biomass should be under 100 Bq/kg [68]. In the meantime, Forestry Agency's study [69] has shown that a forest with an air dose level (1 m above ground) of 0.3 μSv/h has about 7000 Bq/kg contained in leaves, about 980 Bq/kg in tree bark, and about 12 Bq/kg in timber. While in a forest with an air dose level (1 m above ground) of 0.12 μSv/h, the number decreases to about 990 Bq/kg in leaves, 300 Bq/kg in tree bark, and 8 Bq/kg in timber. If we remove the leaves that have high radiation levels and burn them separately, the total wood radiation concentration can be controlled to be within 308 Bq/kg when the air dose level is 0.12 μSv/h in the forest. Therefore, in this study, we proposed additional criteria for selecting the available forests in Fukushima as follows.

$$\text{Air dose rate (1 m above ground)} < 0.1\ \mu\text{Sv/h}$$

We obtained monitoring information of environmental radiation levels from Nuclear Regulation Authority for Fukushima [70]. The latest data obtained on December 11, 2013 at 12:00 (3228 points) was downloaded for radiation levels prediction. We used the following equation for physical decay (half-life) calculation for Cs134 and Cs137:

$$N_t = N_0 \times 0.5^{\frac{t}{T}} \quad (4)$$

where N_t is the radiation level at time t in μSv/h, N_0 is the original radiation level at $t = 0$ in μSv/h, t is the time passed from $t = 0$ in a year, T is the half-life time in years (Cs134, 2 years; Cs137, 30 years). Based on the different dosage contribution rates by Cs134 and Cs137, we calculated their composite radiation level using the following equation:

$$\mathrm{R} = \mathrm{Cs134} \times 70\% + \mathrm{Cs137} \times 30\% \quad (5)$$

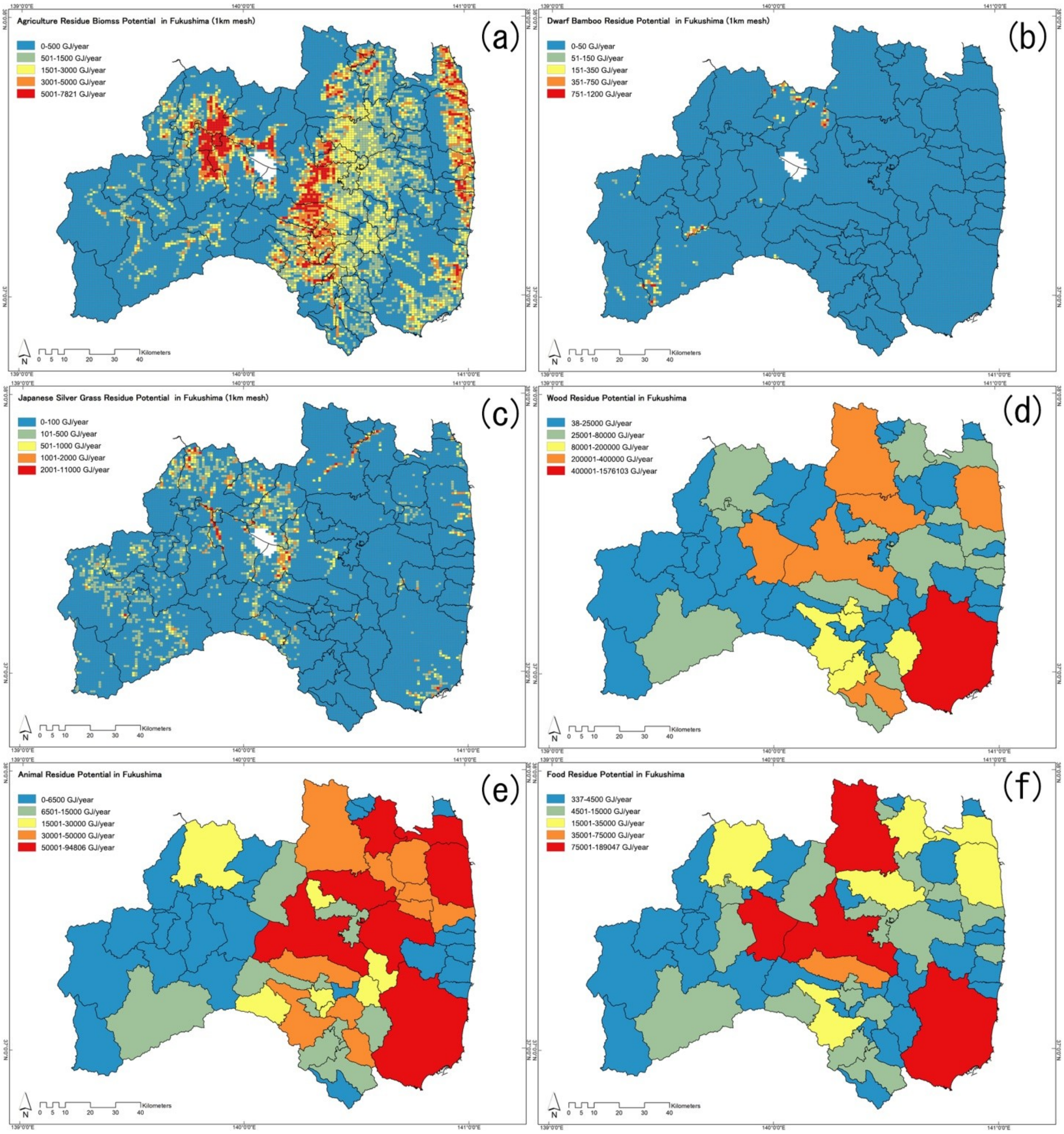
where R is the composite radiation level in μSv/h, *Cs134* is radiation level of Cs134 at time t in μSv/h, and *Cs137* is the radiation level of *Cs137* at time t in μSv/h.

In addition to physical decay, according to the 4th (5 November 2011) and 6th (16 November 2012) airborne monitoring results, there is an additional natural decay rate of 15% per year [71], due to rain and wind effects. Thus, we added this annual natural decay rate to the prediction at 7.5%, which is half of the airborne monitoring results.

Radiation levels at all the 3228 points were predicted for 2020 and 2030 based on the above calculation. Following the first to sixth Environmental Radiation Monitoring and Mesh Survey conducted by Fukushima government [72], we carried out Inverse Distance Weighted (IDW) analysis based on this point data in GIS and then obtained a raster radiation map (resolution 100 m) for 2020 and 2030 in Fukushima. We chose 100 m resolution to be consistent with the following geothermal density raster map's resolution (100 m, provided by Japanese Ministry of Environment) in Section 5.2.4. We subsequently extracted those areas that would have less than 0.1 μSv/h in the years 2020 and 2030.

Residue biomass derived from waste includes forest residue, agricultural residues, solid wood waste, animal residue, and food waste. Efficient use of bio-energy can improve the quality of life in rural areas [30]. We obtained residue biomass data at both 1 km mesh and municipal level from NEDO [67]. There were six sources of residue biomass included in the data. These are agricultural residues (rice straw and chaff), dwarf bamboo, and Japanese silver grass residue at Japanese standard 1 km mesh level. Others are wood residue (construction, sawmill, and park thinning), animal residue, and food residue at municipality level. Municipalities' data was in ".xls" format, to ensure GIS operating speed and provide convenience and efficiency for subsequent calculations. Instead of joining it with current municipality polygons, we chose to convert ".xls" data into ".dbf" data format that can be directly written and read by GIS. We first opened the original ".dbf" data of municipality polygons using Microsoft Excel 2010. We then copied municipalities' residue data from the downloaded ".xls" file into it according to municipal ID, saved it in ".xlsx" format, and converted it into ".dbf" data using Microsoft Access 2010. Finally, we replaced the original ".dbf" data with the new one. The above six sources of biomass had already been summarized in both theoretical and available potential in GJ/yearby NEDO, thus we did not conduct available potential estimation for them. See Figure 7 for the six residue biomass theoretical potential maps.

Figure 7. (**a**) Agricultural residue theoretical potential; (**b**) Dwarf bamboo theoretical potential; (**c**) Japanese silver grass residue theoretical potential; (**d**) Wood residue theoretical potential; (**e**) Animal residue theoretical potential; (**f**) Food residue theoretical potential.



We used the same data that include Fukushima municipalities' boundaries, topography, designated areas, and land use datasets as we used for solar potential estimation in Section 5.2.1. Data relative to vegetation and the forest was as follows. The fifth vegetation survey (polygon, 1:50,000) [73], forest growth (polygon, 1 km) [67], residue biomass (polygon 1 km; in the form of ".xls" file, converted to ".dbf" format to update GIS polygon data as mentioned above) [67], and radiation levels data obtained from Nuclear Regulation Authority [70].

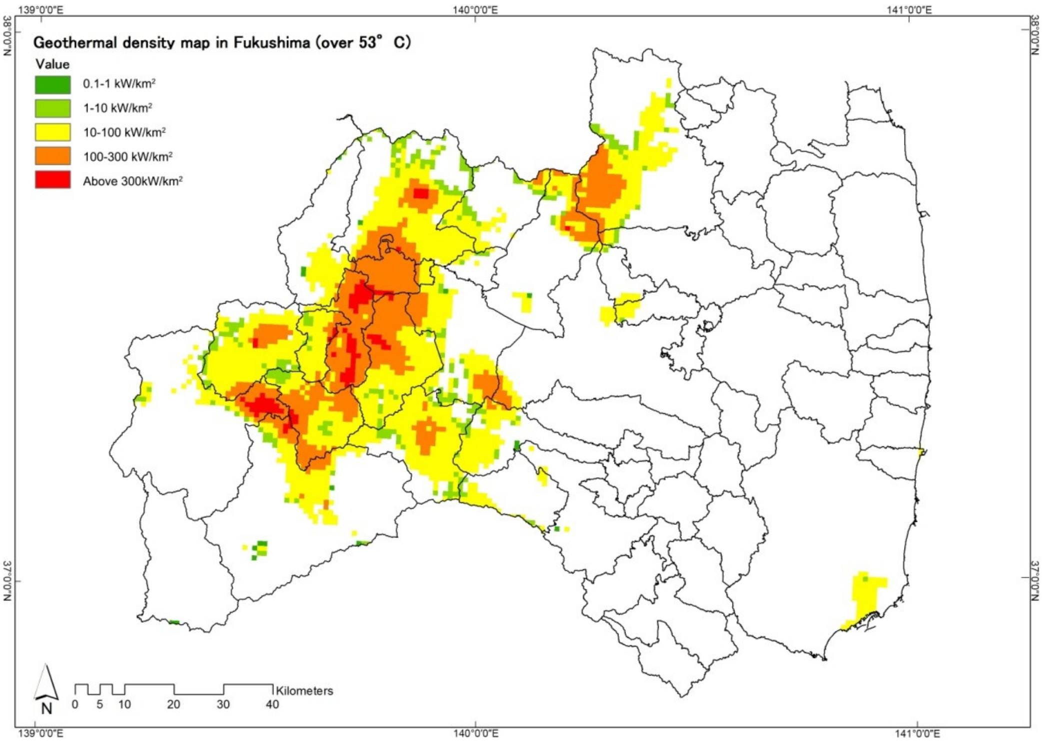
5.2.4. Geothermal

Geothermal potential greatly depends on geological conditions. Factors such as subsurface temperature at a depth of 500–3000 m, soil and bedrock layers, and ground water conditions should be considered [5]. We obtained geothermal density raster map (resolution 100 m) from Basic Zoning Information (2012) of RE by Japanese Ministry of Environment [74]. We first converted the 100 m raster into a new polygon using "raster to polygon" tool in GIS. Secondly, we spatial joined the new polygon data with Japanese standard 500 m mesh, see Figure 8. We then estimated geothermal potential within a new field using the Field Calculator based on the following equation:

$$Q = G_\rho \times S \times 8760 \times \eta \quad (6)$$

where Q is the geothermal potential in kWh/year, G_ρ is the geothermal density in kW/km^2, S is the land area in km^2. The total hours in one year is 8,760 while η is the energy efficiency factor of geothermal power plant; we set η as 70% [75].

Figure 8. Geothermal density map in Fukushima (over 53 °C).



Temperatures above 50 °C are applicable for geothermal exploitation, but high-temperatures (>150 °C) are needed for large geothermal power plants. An empirical case has shown that low-temperatures geothermal (about 50–120 °C) is possible for district heating [76]. Low-temperature geothermal resources are often developed as hot-springs in Japan. Taking into account the impacts geothermal development might bring to local hot spring (On-Sen) businesses, and the average horizontal offset distance of inclined geothermal wells, we set a distance for buffers to the current hot-spring tourism areas. The criteria for available geothermal potential estimation are as follows.

- Temperature >50 °C [61,76]
- Slope < 20°.

- Non-urbanization areas.
- Exclude superior agricultural areas, protected forest areas, natural preservation areas, national parks (special preservation areas), and wildlife conservation areas assigned by relative laws in Japan.
- Un-available land use: rice fields, built-up areas, roads, railways, rivers and lakes, golf courses, and others (airports, and artificial landfill areas among others). Available land use: other agricultural areas (fruit orchards among others), forests, barren lands, and beaches.
- Buffer distance: current hot-spring tourism areas >1,000 m [77].
- Land area size >0.5 ha [77].

We used the same data that include Fukushima municipalities' boundaries, topography, designated areas, and land use datasets as we used for solar potential estimation in Section 5.2.1. Geothermal density map (>53 °C) was obtained from Basic Zoning Information (2012) [74] in raster data format.

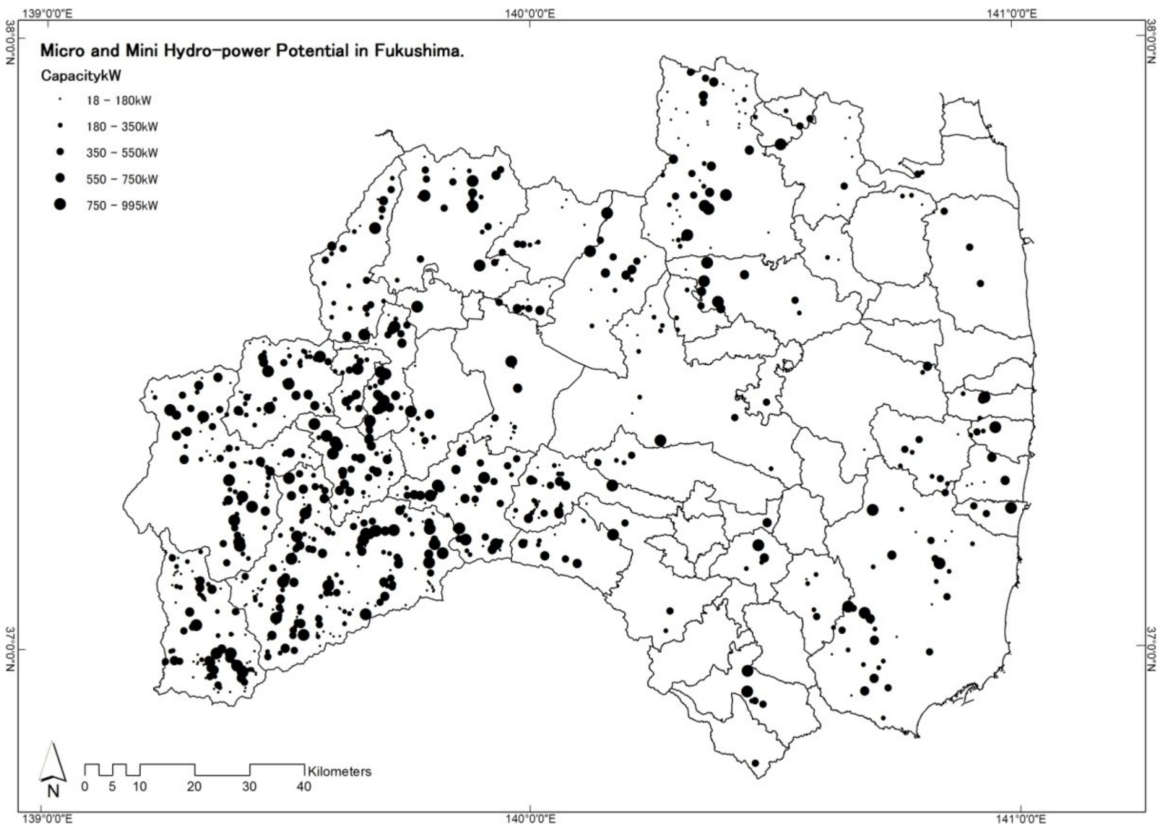
5.2.5. Hydro-Power

In this approach, we only considered micro (0–100 kW) and mini (100–1000 kW) hydro systems. We exported a micro and mini hydro-power potential point map from the Basic Zoning Information (2012) of RE by the Ministry of Environment [74], see Figure 9. We used the following equation to estimate hydro-power potential within a new field using the Field Calculator:

$$Q = W \times 8760 \times \eta \quad (7)$$

where Q is the potential of hydro-power in kWh/year, W is potential hydro-power output in kW, 8760 is the total hours in one year, and η is the hydraulic energy efficiency factor; we set η as 50% [78].

Figure 9. Mini and micro hydro-power output potential in Fukushima.



For available hydro-power estimation, we used the following criterion for exclusion: Superior agricultural areas, protected forest areas, natural preservation areas, national parks (special preservation areas), and wildlife conservation areas as designated by relative laws in Japan [79].

We used the same data that include Fukushima municipalities' boundaries, topography, designated areas, and land use datasets as we used for solar potential estimation in Section 5.2.1. A mini and micro hydro-power output potential map was derived from hydro-power potential map [74].

5.3. Energy Self-Sufficiency Analysis

In this step, we summed all the above available RES potential in 500 m mesh as follows. We spatially joined polygon data (municipal polygon, Japanese standard 500 m or 1 km mesh that have uniform geographic position) with Japanese standard 500 m mesh. Through conversion of raster data (100 m) into polygon data and by spatially joining it with Japanese standard 500 m mesh, we uniformed raster data into the same 500 m mesh. We also spatially joined point data with Japanese standard 500 m mesh. In this way, polygon, raster, and point data have all been uniformed into Japanese standard 500 m mesh layer. We finally summed the available RES potential using Field Calculator in this new 500 m mesh layer. See Table 2 for data processing procedure and tools used. We assumed all the potential will be used for energy self-sufficiency rate calculation. We then overlaid it with primary energy consumption map for 2020 and 2030, respectively (500 m mesh). Energy self-sufficiency rate was calculated by dividing primary energy consumption by the total RE potential using GIS. We classified areas into three categories: (1) high self-sufficiency areas: score 0–0.8 with possible self-sufficiency rate >125%; (2) medium self-sufficiency areas: score 0.8–1.25 with possible self-sufficiency rate between 80%–125%; (3) low self-sufficiency areas: score above 1.25 with possible self-sufficiency rate under 80%. We then visualized these areas using GIS.

5.4. Composite Map Preparation

In spite of the final self-sufficiency mesh map, the available potential vector maps generated in Section 5.2 for each RES can also be used to identify suitable sites under various environmental and socio-economic constraints. After overlays with different criteria, we generated available potential vector maps for mega-solar, wind, forest, geothermal, and hydro-power based on inter-output data (see Table 2). Then, we added all these maps in one data view in GIS to generate one composite map. The composite map can support comprehensive analysis for energy planning. Additionally, we included the current RE facilities in Fukushima into the map. Heat cannot be transferred through long distances; its maximum transferable distance is about 10 km [28]. We added 10 km buffers for possible heat transfer areas based on each centre of the high geothermal potential spots. To provide more relative information and improve the visual experience of the composite map, we also added the boundaries for evacuation-directed zones and hatched urban areas in the composite map.

5.5. Decision Making Support: Renewable Energy Plan Making

Self-sufficiency maps and composite potential sites maps can be produced at the regional level through the above steps. These maps can facilitate understanding of energy demand-supply relationship and indicates possible sites for different RES to planners, investors, and policy makers. This, therefore, can also provide decision making support for future RE plan making in Fukushima.

Table 2. Data processing procedure and tools used in this study.

Input Data	Format/ Resolution or scale	Tool	Inter Output Data	Tools (For criteria overlay)	Final Output Data
Population	Polygon/ 1:25,000	Field Calculator	Population and Primary energy consumption in municipal polygon	Spatial join	Population and Primary energy consumption in 500 m mesh*
Average annual solar radiation	Polygon/ 1 km mesh	Field Calculator	Solar potential in 1 km mesh	Erase or Clip Field Calculator Spatial join	Solar potential in 500 m mesh
Wind speed	".dat"	Fishnet tool Microsoft Excel and Access Field Calculator	Wind speed in 500 m mesh (.dbf)	Erase or Clip Field Calculator Spatial join	Wind speed in 500 m mesh
Annual forest growth	Polygon/ 1 km mesh	Field Calculator	Wood biomass potential in 1 km mesh	Erase or Clip Field Calculator Spatial join	Wood biomass potential in 500 m mesh
Radiation	Point	IDW analysis Raster to polygon	Polygons for forest areas under 0.1 μSv/h	-	-
Residue (agriculture, dwarf bamboo *etc.*)	Polygon/ 1 km mesh	-	Residue (agriculture, dwarf bamboo *etc.*) in 1 km mesh	Spatial join	Residue (agriculture, dwarf bamboo *etc.*) in 500 m mesh
Residue (wood, animal *etc.*)	".xls"	Microsoft Excel and Access	Residue (wood, animal *etc.*) in Municipal polygon (.dbf)	Spatial join	Residue (wood, animal *etc.*) in 500 m mesh
Geothermal density	Raster map/100 m	Raster to polygon Field Calculator	Geothermal potential polygon map	Erase or Clip Field Calculator Spatial join	Geothermal potential in 500 m mesh
Hydro-power	Point	Field Calculator	Hydro-power potential in point data	Erase or Clip Spatial join	Hydro-power potential in 500 m mesh

* Note: all 500 m (1 km) mesh in this table refers to Japanese standard 500 m (1 km) mesh.

6. Results and Discussion

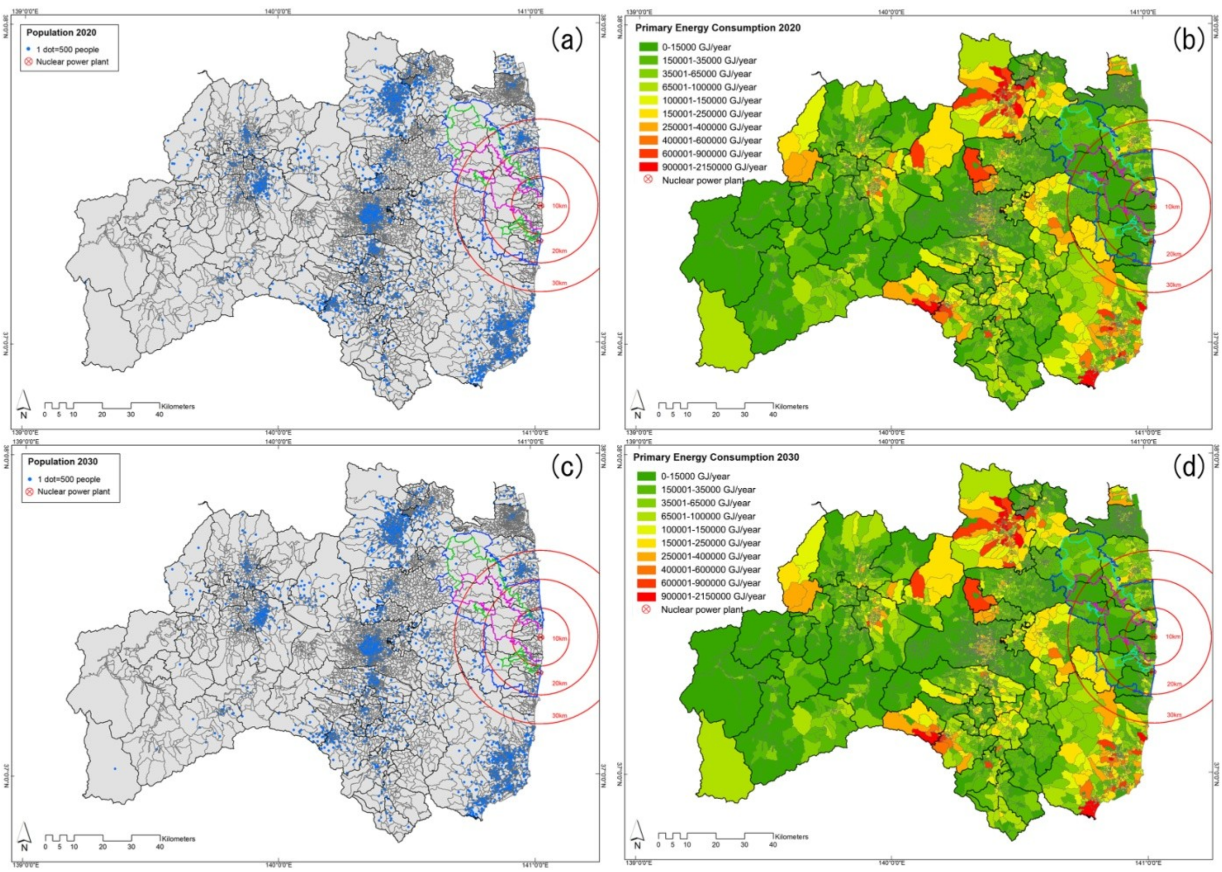
6.1. Primary Energy Consumption

Population and primary energy consumption prediction for 2020 and 2030 are as follows. Except for Soso region, which is expected, to have an increase in population from returning evacuees by 2030, there will be a population decrease trend in all the other regions of Fukushima between 2010 and 2030. See Table 3. Population and primary energy consumption are illustrated in pairs for 2020 and 2030, see Figure 10.

Table 3. Population and primary energy consumption prediction results for 2020 and 2030 in Fukushima.

Region	Sub-Region	Population			Primary Energy Consumption (GJ/year)		
		2010	2020	2030	2010	2020	2030
Aizu	Aizu	262,051	249,117	223,607	42,791,559	41,304,906	38,666,877
	Minami-Aizu	29,893	27,645	24,814	4,881,163	4,583,692	4,290,945
Naka-doori	Kenpoku	497,059	474,225	425,860	81,166,125	78,628,979	73,641,111
	Kenchu	551,745	523,803	470,245	90,095,740	86,849,387	81,316,276
	Kennan	150,117	140,001	125,665	24,512,959	23,212,869	21,730,327
Hama-doori	Soso	202,773	142,009	142,823	33,112,178	23,545,885	24,697,479
	Iwaki	342,249	338,636	303,959	55,886,443	56,147,587	52,561,597
Total		2,035,887	1,895,436	1,716,973	332,446,167	31,423,305	296,904,612

Figure 10. Fukushima's population in 2020 (**a**) and 2030 (**c**); Fukushima's primary energy consumption in 2020 (**b**) and 2030 (**d**); Colored lines shows evacuation directed areas. Red circles are the 10–30 km buffers from Fukushima Daiichi nuclear power plant.



6.2. Renewable Energy Potential

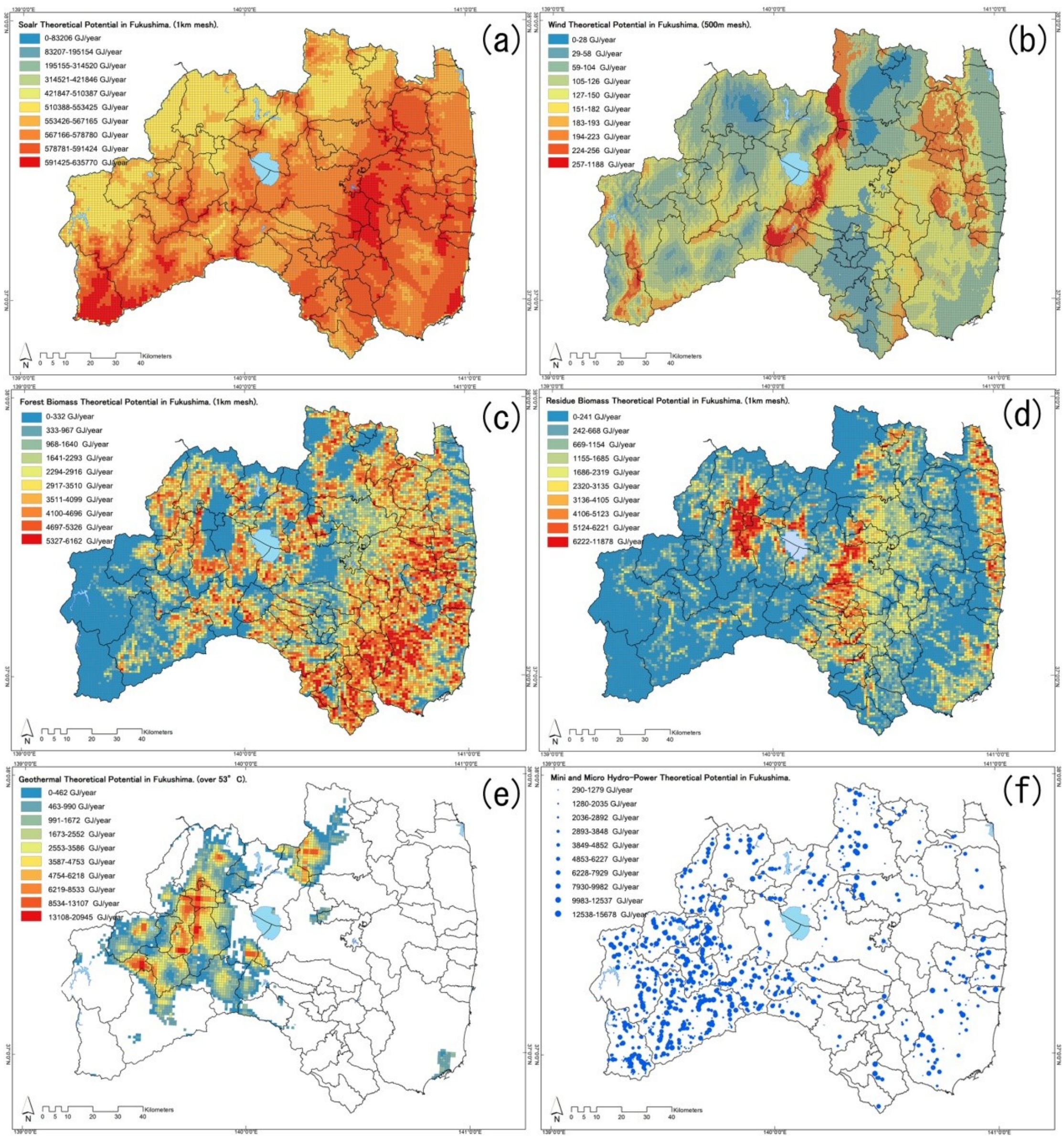
6.2.1. Theoretical Renewable Energy Potential

The theoretical RE potential has been summarized in Table 4. Solar power has the highest theoretical potential among all the five RES in Fukushima. Biomass is second while wind power is in third place. Their spatial distribution has been characterized as well, see Figure 11.

Table 4. Summary of Theoretical Potential in Fukushima.

Region	Sub-Region	Solar (GJ/year)	Wind (GJ/year)	Biomass (GJ/year)		Geothermal (GJ/year)	Hydro-power (GJ/year)
				Forest	Residue		
Aizu	Aizu	1,649,380,413	1,335,567	5,672,292	6,765,281	4,031,570	1,734,745
	Minami-Aizu	1,301,851,592	1,205,125	1,851,971	2,098,939	921,606	2,761,851
Naka-doori	Kenpoku	875,823,528	785,558	3,531,325	4,750,331	467,028	462,833
	Kenchu	1,454,652,744	1,533,576	6,679,078	8,283,394	143,910	359,587
	Kennan	690,962,002	553,976	3,952,520	4,956,428	19,249	152,787
Hama-doori	Soso	985,262,414	1,059,140	4,897,303	5,761,468	1238	238,846
	Iwaki	689,691,755	606,831	4,113,452	5,984,101	35,257	243,585
Total	-	7,647,624,448	7,827,791	30,697,941	38,599,942	5,619,858	5,954,234

Figure 11. (**a**) Solar theoretical potential; (**b**) Wind theoretical potential; (**c**) Forest biomass theoretical potential; (**d**) Residue Biomass theoretical potential; (**e**) Geothermal theoretical potential; (**f**) Hydro-power theoretical potential.



6.2.2. Available Renewable Energy Potential

As mentioned before, available forest area under 0.1 μSv/h is affected by radioactive materials' physical and natural decay conditions. Available forest areas will greatly increase from year 2013 to 2020. On the other hand, it will increase comparatively slowly from 2020–2030. This is because those areas originally with high radiation levels will still be above 0.1 μSv/h even 20 years after Fukushima Daiichi Crisis in 2011, see Figure 12. After overlaying different criteria (expect for residue biomass), the available RE potential has been quantified, see Table 5. Furthermore, available sites with different potentials have been identified for each RES as well, see Figure 13.

Figure 12. Radiation and forest map in 2013 (**a**); 2015 (**b**); 2020 (**c**); 2023 (**d**); 2028 (**e**); 2030 (**f**) in Fukushima. Aqua blue indicates areas under 0.1 μSv/h while grey indicates areas above 0.1 μSv/h. Green areas are the available forest areas before taking into account radiation conditions.

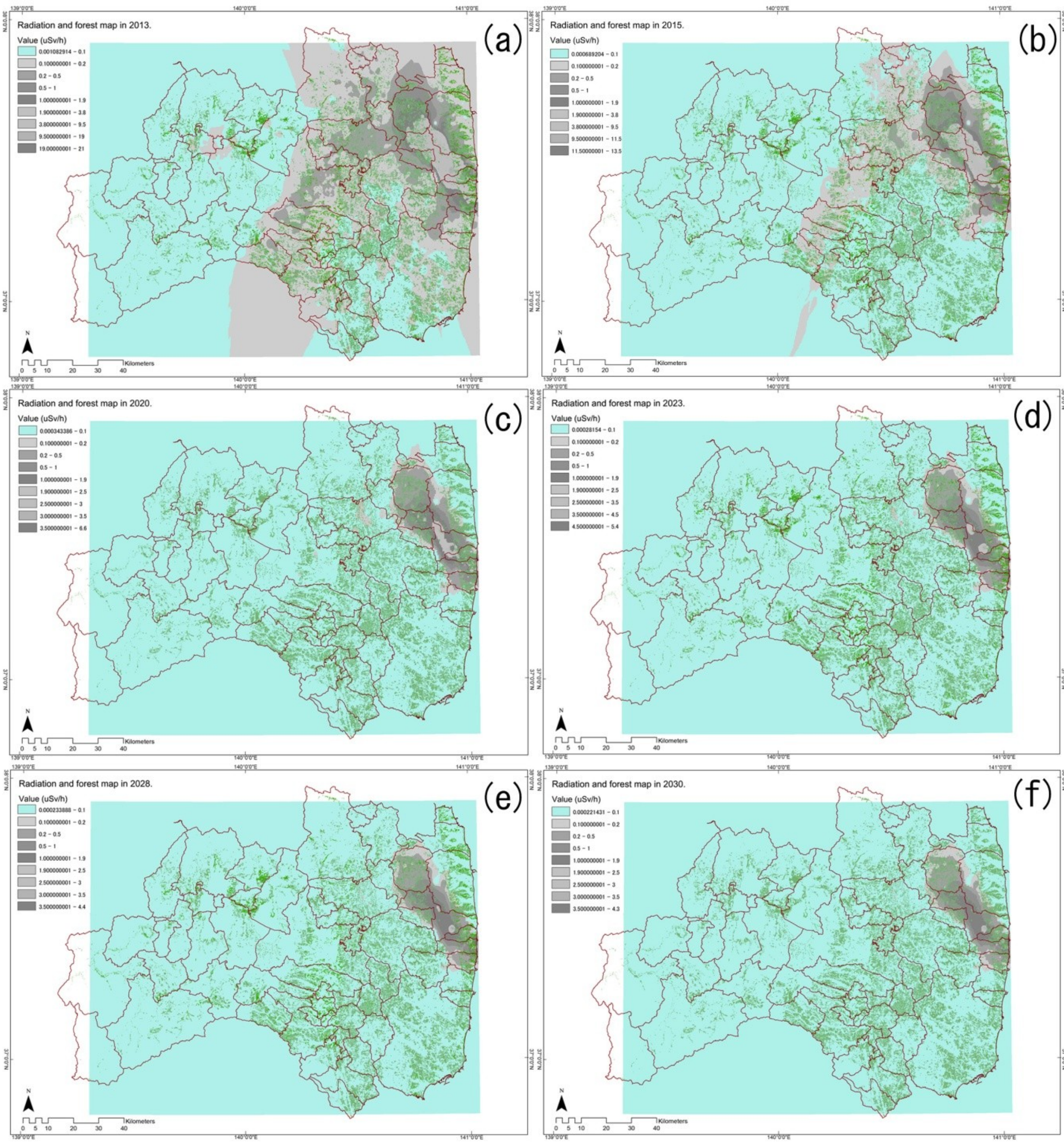
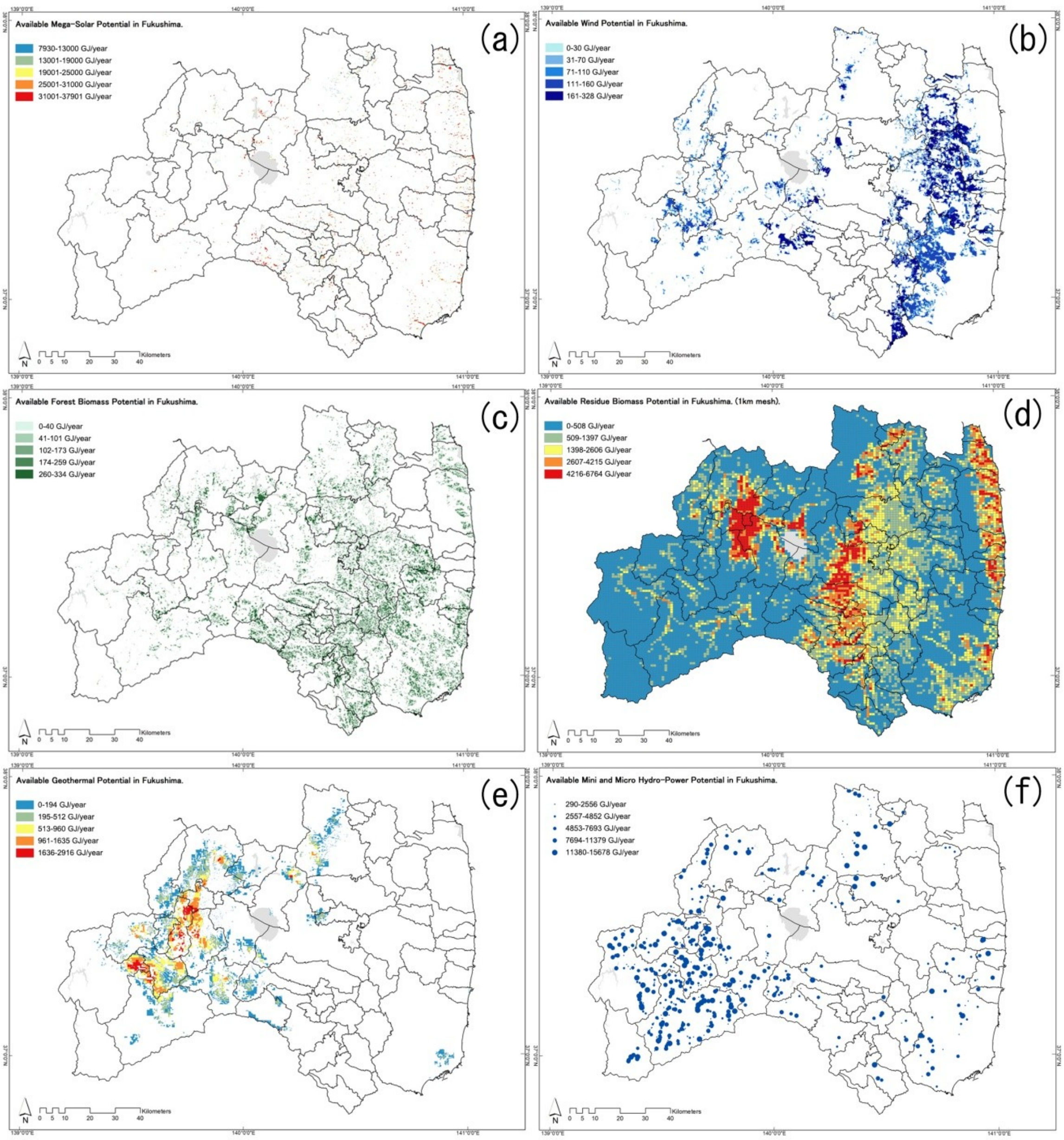


Table 5. Summary of Available Potential in Fukushima.

Region	Sub-Region	Mega-Solar (GJ/year)	Wind (GJ/year)	Biomass (GJ/year)		Geothermal (GJ/year)	Hydro-power (GJ/year)
				Forest (2020)	Residue		
Aizu	Aizu	12,155,400	93,742	1,143,591	2,742,340	1,664,734	1,244,265
	Minami-Aizu	2,612,457	45,108	348,803	464,288	499,986	1,724,135
Naka-doori	Kenpoku	8,449,481	61,982	946,895	1,304,350	89,005	245,175
	Kenchu	21,018,417	273,709	2,764,895	3,242,402	42,183	225,566
	Kennan	16,376,603	83,800	1,606,596	1,163,934	11,474	92,090
Hama-doori	Soso	28,279,549	302,983	992,506	1,834,251	724	124,723
	Iwaki	14,234,210	151,444	1,610,949	837,067	11,873	187,230
Total	-	103,126,117	1,012,768	9,414,235	11,588,632	2,319,979	3,843,184

Figure 13. (**a**) Available solar potential; (**b**) Available wind potential; (**c**) Available forest biomass potential; (**d**) Available residue biomass potential; (**e**) Available geothermal potential; (**f**) Available mini and micro hydro-power potential.



6.3. Energy Self-Sufficiency Map

We generated energy self-sufficiency maps for 2020 and 2030 by overlaying primary energy consumption map and all RE available potential maps, see Figure 14. By the end of 2020, 39.7% of areas have potential to become high self-sufficiency areas, 4.7% of areas have potential to become medium self-sufficiency areas, while the rest 55.6% are in the low self-sufficiency category. Most of the high self-sufficiency areas (23.1%) are distributed in Aizu region, medium self-sufficiency areas are almost evenly distributed; Aizu (1.8%), Naka-doori (1.5%), and Hama-doori (1.5%). Most of the low self-sufficiency areas (28.1%) are distributed in Naka-doori region. By the end of 2030, high self-sufficiency level in Soso region slightly decreases by 1.2% compared to 2020, due to increase in evacuees return to this region. Consequently, both the levels of medium and low self-sufficiency slightly increase mainly in Soso region. See Table 6.

Figure 14. (**a**) Energy self-sufficiency map for Fukushima in 2020; (**b**) Energy self-sufficient map for Fukushima in 2030.

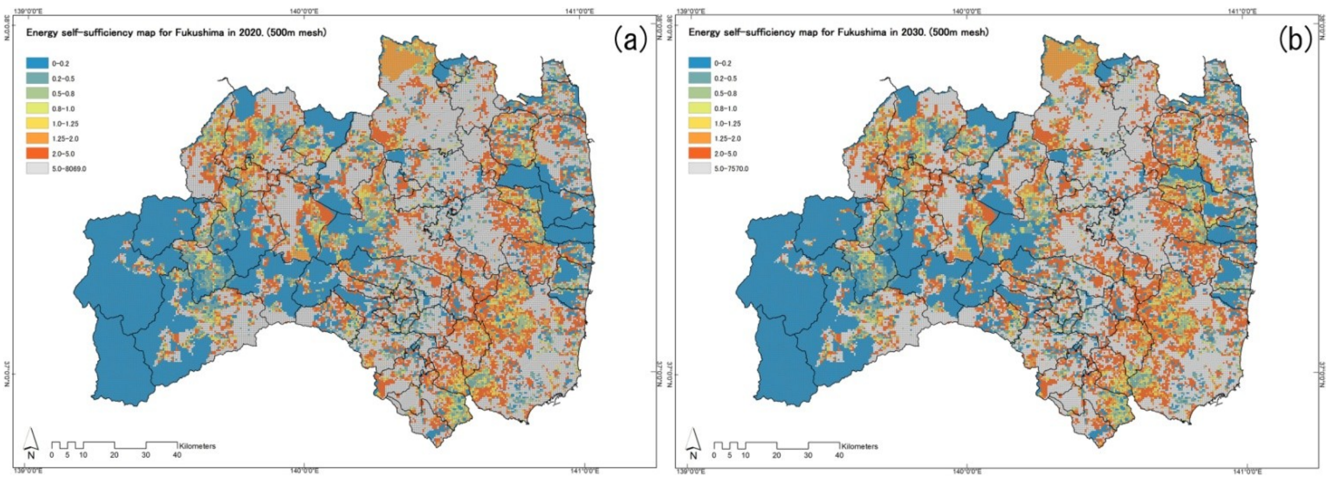


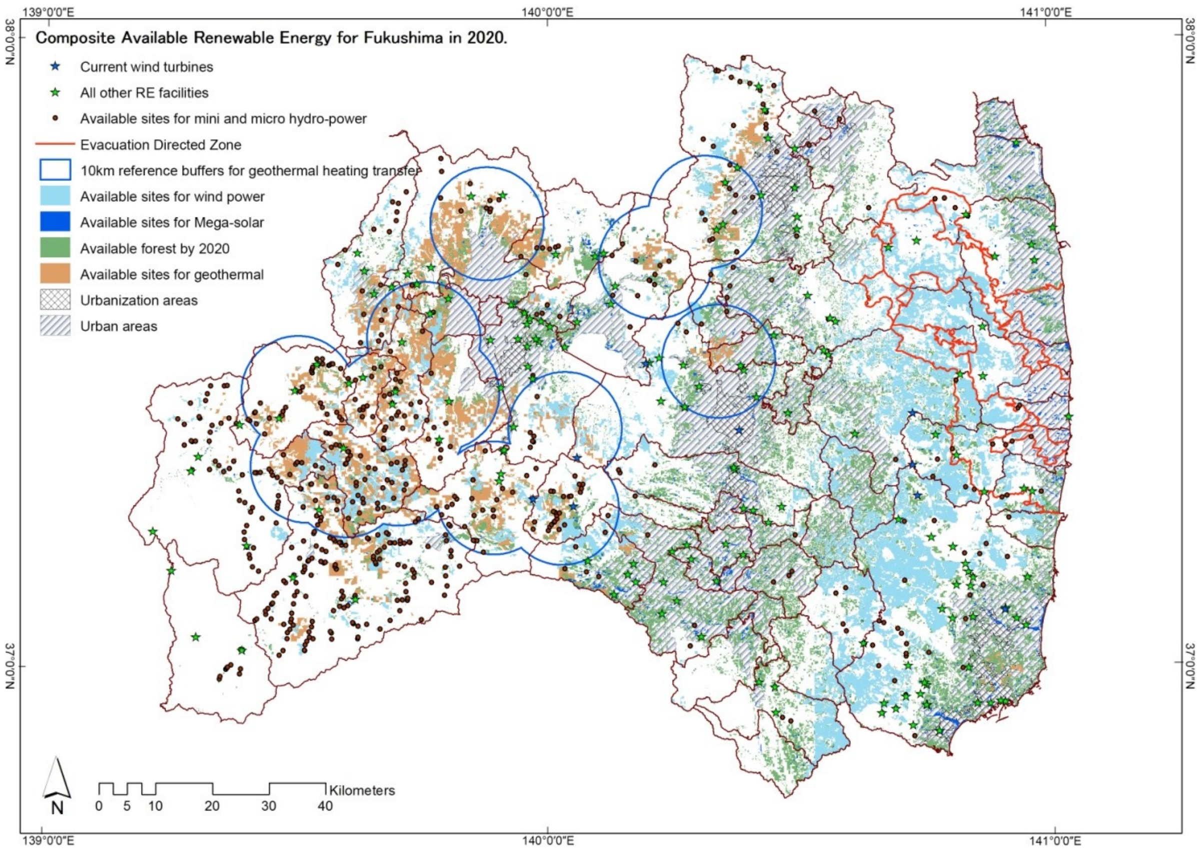
Table 6. Distribution of self-sufficiency areas in Fukushima by 2020 and 2030.

Region	Sub-Region	High self-sufficiency area		Medium self-sufficiency area		Low self-sufficiency area	
		2020	2030	2020	2030	2020	2030
Aizu	Aizu	10.0%	10.1%	1.5%	1.4%	11.0%	10.9%
	Minami-Aizu	13.1%	13.1%	0.3%	0.3%	3.7%	3.6%
Naka-doori	Kenpoku	1.9%	1.9%	0.4%	0.4%	10.4%	10.3%
	Kenchu	5.1%	5.1%	0.6%	0.8%	11.4%	11.3%
	Kennan	2.1%	2.2%	0.5%	0.5%	6.3%	6.3%
Hama-doori	Soso	6.0%	4.8%	0.6%	0.9%	6.2%	7.1%
	Iwaki	1.5%	1.5%	0.8%	0.8%	6.6%	6.7%
Total	-	39.7%	38.7%	4.7%	5.1%	55.6%	56.2%

6.4. Composite Analysis Map

Following the approach in Section 5.4, we generated a composite map that shows available potential maps and other related information (urban areas, and buffers for heat transfer among others) using GIS. We used the available forest by 2020, to generate a sample map, see Figure 15. In Figure 15, it is shown that available geothermal and hydro-power potential sites are mainly distributed in western Fukushima, while wind and forest biomass are mainly distributed in Eastern Fukushima. Evacuation Directed Zones have many available sites for developing wind energy. Some urban areas are within the radius of 10 km buffer for heat transfer, which means there is potential for using low-temperature geothermal resources for district heating in residential areas.

Figure 15. Composite available renewable energy potential map for Fukushima in 2020.



In regard to the spatial planning concept inclusion into RE planning, the next phase of this study rests on developing a multi-criteria evaluation method to identify optimal locations for large scale RE facilities. It focuses on an integrated spatial planning approach to organize environmental and socio-economic impacts and benefits. This is followed by conducting scenario analysis for different anticipated effects based on a region's ability to meet its RE objectives. We propose the following guidelines to be considered in the RE spatial planning process. (1) Sustainability: thinking about the future, and long-term development; (2) Energy flow: planning for energy transfer from comparatively high self-sufficiency to low self-sufficiency areas. Energy flow can be flexibly planned for, between low self-sufficiency and high self-sufficiency areas based on the actual local conditions; (3) Energy efficiency and distance: energy efficiency has three meanings, efficient energy production, efficient energy transfer, and efficient use of energy. Jabareen [80] pointed out that "energy efficiency is a key to achieving ecological form through design on the building, community, city, and regional levels". Ecological spatial form designed for long life could help with organizing time and space in order to reduce energy usage. Under the spatial planning concept, we may plan for efficient energy transfer through spatial organization. This is particularly the case for heating resources that can only be transferred within a limited distance [6,28], which can be combined with development plans in areas such as housing and industrial parks among others; (4) Impacts and benefits: the increase in scale and number of RE facilities would bring both impacts and benefits. This include issues such as the visual impact created by big wind turbines, as well as job creation benefits [41,42] resulting from different types of RE development. In the future, regional or city scale comprehensive evaluation should be considered in the RE spatial planning process, in order to balance social, economic, and ecological requirements for different areas; (5) Public participation: This is an important part of spatial planning. Informative visualization provided by GIS-based analysis could be used in a participatory process for energy planning.

7. Conclusions

Based on the results of this study, we made the following conclusions:

- In Fukushima, except for the Soso region, which may have an increase in population due to returning evacuees by 2030, there will be a decrease in population in all the other regions between 2010 and 2030. In regard to RE potential, solar power has the highest theoretical potential among all the five RES; biomass is second, while wind power is in third place. Mega-solar has the highest available potential, biomass, mini and micro hydro-power takes second and third places, respectively. Available forest areas will greatly increase from year 2013–2020. On the other hand, they will increase comparatively slowly from 2020–2030. This is because those areas originally with high radiation levels will still be above 0.1 μSv/h even 20 years after Fukushima Daiichi Crisis in 2011. By the end of 2020, 39.7% of Fukushima areas will have potential to become high self-sufficiency areas, 4.7% will have potential to become medium self-sufficiency areas while the remaining 55.6% will be in the low self-sufficiency category. By the end of 2030, high self-sufficiency levels in the Soso region will slightly decrease by 1.2% compared to 2020, due to increase in evacuees return to this region.
- The proposed GIS-based approach is useful in providing quantification and visualization of information in support of decision making for spatial planning of RE. The results of the case study in Fukushima confirm that, with the proposed approach, it is possible to identify future potential energy self-sufficiency possibilities with energy self-sufficiency map. Likewise, low self-sufficiency areas that need energy importation through spatial organizations in a long-term vision can also be identified. The composite map for available renewable energy revealed potential sites for developing RE facilities in the future. It also characterized their spatial distribution relationship, thus providing more accurate and integrated information for planners, investors, and policymakers.
- Because only installation objectives have been set for various RE facilities in Fukushima, the study results show possibilities and capabilities on how to achieve these goals. The results of this study show the need to explore multiple RES to meet those goals, and to increase energy safety and independence in Fukushima.
- The process of evaluating self-sufficiency possibilities and identifying potential sites for RE at the regional scale can further be applied to other Japanese municipalities or regions. Other

criteria for available potential estimation and RES can further be included based on local, regional, and actual conditions. As RE are expected to play a key role in post-earthquake redevelopment in Fukushima and other regions, more municipalities and communities will embrace RE planning aimed at increasing energy independence. We reckon that municipalities and communities shall be best-informed through GIS-based integrated analysis, and hence make the most appropriate decisions in the planning process.

Acknowledgments

We thank all the members of Laboratory of Spatial Planning (Town and Country Planning) in the Graduate School of Horticulture, Chiba University for their advice and other inputs. We thank Kexin Li for assisting with illustration layout. We also thank all the departments that have provided online data download service, especially the Japanese Ministry of Environment for providing a GIS data CD-ROM on Basic Zoning Information for Renewable Energy (2012).

Author Contributions

Qianna Wang made substantial contribution to the study design, acquisition and analysis of data, and in drafting and revision of the manuscript. Martin Mwirigi M'Ikiugu provided a wide range of advice and support throughout the study. He helped to draft, edit, and revise the manuscript. He also provided the core contribution on spatial planning and urban-rural issues discussion in Japan, especially in Section 2 of this article. Isami Kinoshita supervised and guided this work. He provided advice during the study, and helped with manuscript revision.

Conflicts of Interest

The authors declare no conflict of interest.

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