GIS-BASED SPATIAL PLANNING OF RENEWABLE ENERGY: TOWARDS FUTURE SUSTAINABILE SOCIETY

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GIS を利用した再生可能エネルギーの空間計画に関する研究：持続可能な社会の構築に向けて

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Abstract

Renewable Energy is receiving increasing attention for its clean, green, and safe characteristics. It drives energy structure towards a sustainability level by providing a sustainable approach to energy generation, and contributing to mitigation of the green effect in the long term. The spatial distribution of Renewable Energy Resources is strongly affected by geographic and topographic factors. Therefore, the exploration and supply of Renewable Energy should be carefully planned at the local or regional levels based on different factors. In the meantime, along with the increasing size and number of Renewable Energy facilities, the impacts on landscape they are bringing is also put forth a challenging task for landscape architecture research and practical fields.

Geographic Information Systems (GIS) have proved to be a useful tool for regional Renewable Energy potential estimation and support for decision-making in energy planning. However, the full introduction of GIS-based approach in support of spatial planning for Renewable Energy at regional level has not been well utilized until now. In this context, this study aims to: 1) present a GIS-based approach in support of spatial planning for Renewable Energy at regional level, by providing information on regional potentials and restrictions to different energy stakeholders; 2) consider the impact of Renewable Energy facilities on landscape, such as the visual impact of wind turbines; and 3) preliminary study on Renewable Energy's role in sustainability.

The results of this study contribute the proposed that a GIS-based approach in support of spatial planning for Renewable Energy. The proposed approach is expected to be applied to other Japanese municipalities or regions, and other regions worldwide. This study highlights that some concepts of spatial planning, such as spatial organization for future sustainable development, and consideration for balancing spatial development with social, economic, and ecological requirements, applicable in the Renewable Energy planning field. With the increasing scale and number of Renewable Energy facilities, the visual impact of these should be taken note of and addressed in the planning process as well.

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CHAPTER 1

INTRODUCTION

1.1 Background

Renewable Energy (RE) is energy generated from solar, wind, biomass, geothermal, hydropower, ocean resources, and biofuels (IEA, 2011). The use of RE is becoming popular for its clean, safe characteristics. The development of RE is also one of the crucial steps for future sustainable development of energy resources. Since the introduction of the concept of "sustainable development" at the Rio conference (1992), it has become worldwide popular and gradually is seeping into all aspects of our society. Sustainable energy supply and use plays a key role in the sustainable strategy and it represents a crucial part of the overall strategy of sustainable development (European Renewable Energy Council, 2012). It drives energy structure towards a sustainability level by providing a sustainable approach to energy generation, and contributing to mitigation of the green effect in the long term.

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 (Japanese Ministry of Economy, Trade and Industry, 2010). 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. As a result, 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.

The spatial distribution of Renewable Energy Resources (RES) is strongly affected by geographic and topographic factors. Therefore, exploration and supply of RE should be carefully planned at the local or regional levels based on different factors. In the meantime, along with the increasing size and number of RE facilities, the impacts on landscape they are bringing is also put a challenging task for landscape architecture research and practical fields.

Geographic Information Systems (GIS) have proved to be a useful tool for regional RE potential estimation and support for decision-making in energy planning. However, the full introduction of GIS-based approach in support of spatial planning for RE at regional level has not been well utilized until now. In this context, this study aims to presents a GIS-based approach in support of spatial planning for RE at regional level, while visual impact of RE facilities on landscape has been especially paid attention to. The main contribution of study is to propose a GIS-based approach in support of spatial planning for RE. The proposed approach is expecting to be applied to other Japanese municipalities or regions, and other regions worldwide. This study highlights that some concepts of spatial planning, such as spatial organization for future sustainable development and consideration for balancing spatial development with social, economic, and ecological requirements are probably applicable in the RE planning field.

1.2 Definitions of Key Terms and Their Abbreviations

Renewable Energy: Renewable Energy is energy generated from solar, wind, biomass, geothermal, hydropower, ocean resources, and biofuels, and electricity and hydrogen derived from those renewable resources (IEA, 2011).

Spatial Planning: Spatial Planning refers to the methods used by the public sector to influence the distribution of people and activities in spaces at various scales as well as the location of the various infrastructures, recreation and the nature areas (CEMAT, 2007).

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" (CEMAT, 1983).

Geographic Information System (GIS): A geographic information system (GIS) lets us visualize, question, analyze, and interpret data to understand relationships, patterns, and trends. GIS benefits organizations of all sizes and in almost every industry. There is a growing interest in and awareness of the economic and strategic value of GIS. (ESRI, 2014).

Landscape: landscape means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors (European Landscape Convention, 2004).

Landscape Planning: Landscape planning is an activity involving both public and private professionals, aiming at the creation, conservation, enhancement and restoration of landscapes at various scales, from greenways and public parks to large areas, such as forests, large wilderness areas and reclamation of degraded landscapes such as mines or landfills (CEMAT, 2007).

Environmental Impact Assessment: An environmental assessment is an analysis of the likely impacts that a project may have on ecosystems, human health and on changes to nature's services. The main impacts to be analyzed are: soil contamination impacts, air pollution impacts, noise health effects, ecology impacts including endangered species assessment, geological hazards assessment and water pollution impacts. Other concerning of Environmental Impact Assessment include land use, economic development, and visual aspects etc. (CEMAT, 2007).

Visual Impact: Visual effects relate to the changes that arise in the composition of available views as a result of changes to the landscape, to people's responses to the changes, and to the overall effect with respects to visual amenity (UK National Infrastructure Planning, 2011).

Zone of Visual Influence (ZVI): Area within which a proposed development may have an influence or effect on visual amenity (UK National Infrastructure Planning, 2011).

Sustainability: Development that needs of the present without compromising the ability of future generations to meet their own needs (UN, 1987).

1.3 Research Objectives

The landscape aesthetics during the energy planning process have been paid little attention to. In the meantime, the combination of RE planning/design and landscape is a new research field to Landscape Architecture. The main objective of this study is to provide a relative study in this field, by proposing a methodology of RE spatial planning at regional level for support to decision making in energy planning. Furthermore, the RE's impact on landscape has been taken into account as well.

Specifically, the objectives of this study are as follows,

1) to present a GIS-based approach in support of spatial planning for RE at the regional level, by providing information on regional potentials and restrictions to different energy stakeholders;

2) to consider impact of RE facilities on landscape, such as the visual impact of wind turbines; and

3) a preliminary study on RE's role in sustainability.

1.4 Research Framework

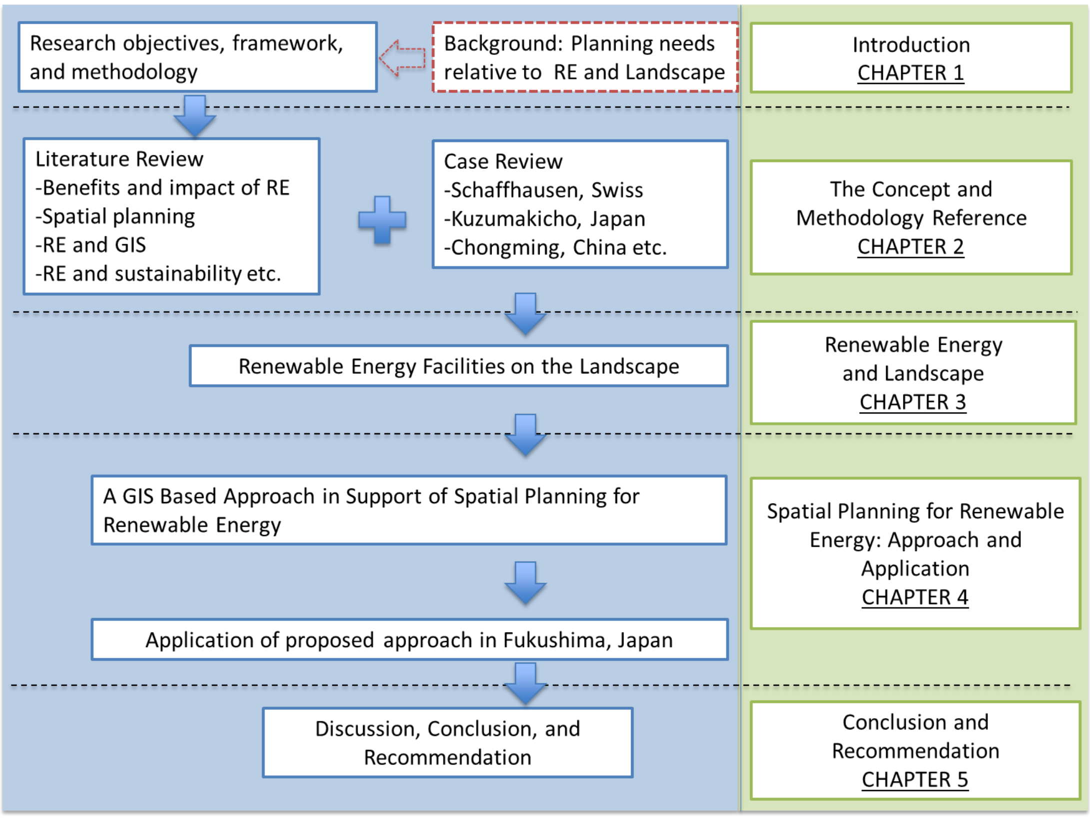

Figure 1. Research framework of this study.

1.5 Brief Description of Chapters

The study is composed of five chapters. Each chapter is briefly described below:

Chapter 1-Introduction

This chapter introduces research background, objective, structure, and methodologies of the study.

Chapter 2-Literature and Case Review

This chapter aims to provide theoretical and empirical references for concept and methodology of the study based literature and case review. Specifically, the benefits and impacts of RE, RE and GIS, RE and spatial planning, and RE and sustainability have been addressed.

Chapter 3- Renewable Energy Facilities on the Landscape: Visual Impact Evaluation of Wind Farms in Choshi city, Japan

Consideration of the aesthetic issues involving RE facilities, specifically, it maybe necessary to take into account landscape consideration in RE spatial planning process, especially for big size wind turbines. Therefore, this chapter focuses on visual impact evaluation of wind farms. Visual impact is considered as one of the main impacts of wind farms, and a leading cause of public opposition. In Japan, attention has been paid to wind farms' visual impact in high scenic value areas such as National Parks, but no attention paid at local levels. This chapter focuses on local areas and proposed a GIS-based integrated methodology for visual impact evaluation of wind farms at both city and community levels. The application of the proposed methodology has been conducted in Choshi city, Japan. A city has the largest number of wind turbines in Japanese Kanto region.

Chapter 4- A GIS Based Approach in Support of Spatial Planning for Renewable Energy

Based on the previous chapters, this chapter presents an approach in support of spatial planning for RE facilities at the regional level. The approach aims to establish an elaborate and informative procedure, as well as integrated quantification and visualization to support decision-making in RE spatial planning. This approach takes a step away 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, multiple RES, potential site analysis at the regional level, and visual impact of wind turbines using GIS. The application of the proposed approach has been conducted in Fukushima Prefecture, Japan, because of the planning needs to support the prefectural future RE developmental vision for 2020 and 2030. Evacuees' population and forest radiation levels are specifically considered in the context of consequent issues emanating from the Fukushima Daiichi nuclear crisis.

Chapter 5-Conculsion and Recommendation

This chapter discusses the findings of Chapters 1-4. The remaining tasks of this study, future tasks, and recommendation are described as well.

1.6 Research Methodology

a. Literature Review

This study reviews literature in the following areas. Benefits and impact of RE, GIS-based RE site selection and potential estimation, RE and spatial planning, and RE and sustainability. The review material resources are from journal articles, selected books and documents, and online reports and documents. The multiple sources of literature provide theoretical and empirical references as well as a basis for the study.

b. Case Study: Selected and Survey Methods

As a research method, the case study had been widely used in social science fields. A case study can enable researchers to understand complex real-life activities in which multiple sources of evidence were found (Noor, 2008). According to Yin (1984), multiple sources of data are important to improve the reliability of case study results. In order to reveal the context and inter-relationship in and between relative advanced cases in this study, the case study method has been used. Specifically, to obtain more information and data, the following surveys were conducted for each corresponding case.

- Schaffhausen, Switzerland (Referencing case): desktop information gathering; on-site and email interview.

Schaffhausen finalized its municipal energy planning (RE included) based on GIS in 2007. As a pioneer and advanced case in Europe, its energy planning making process and methodology are worth to be investigating in detail as a reference to this study.Thus, Schaffhausen has been chosen as one of the case study sites.

- Kuzumakicho, Japan and Chongming Island, China (Referencing cases): desktop information gathering; on-site interview; questionnaire.

They were selected because they are some of the most progressive RE development cases in their respective home country's rural areas. They bear specific characteristics and issues, such as population loss and local business decline in Kuzumakicho, and quick economic and energy consumption increase on Chongming Island.

- Choshi City, Japan (Application case study): desktop information gathering; field survey; on-site interview; questionnaire; GIS analysis.

Choshi has the largest number of wind turbines in Japanese Kanto region. The city has a total wind energy production capacity of 53,560kW (Choshi City Gov., 2010). Between years 2001-2009, wind turbines increased from 1 to 34 within 10 wind farms. The number of wind turbines and wind energy development process along years provide enough information for visual impact evaluation at city level. In addition, settlements in Choshi suburban areas also provide big potential for visual impact evaluation of wind farms at settlement level.

- Fukushima Pref., Japan (Application case study): desktop information gathering; questionnaire; GIS analysis.

Fukushima was selected because of its planning needs to support the prefectural future RE developmental vision for 2020 and 2030. In addition, evacuees' population and forest radiation levels in the context of consequent issues emanating from Fukushima Daiichi nuclear crisis make it worthy for inclusion as a case study, in order to test the flexibility of proposed methodology.

c. Interview and Questionnaire

To deeper investigate the cases, on-site interview, e-mail interview, questionnaire to specific respondents have been conducted in this study.

d. GIS Analysis

GIS have proved a useful tool for RE potential estimation and support for decision making in energy planning. GIS has 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 (Simao et al. 2009). Besides, the Viewshed analysis function in GIS can also be used to identify visual impact areas of wind farms.

GIS analysis has been taken as the basis of proposed spatial planning approach for RE, as well as city level Viewshed analysis tools in evaluating visual impact of wind farms in this study. The GIS data resources comes from multiple databases, they include: open online GIS database and GIS data provided in CD-ROM. Besides, other format of data, such as: ".xls", ".dat", and ".jpg", have been used as one resource of GIS data. These data have been coded, converted into format that can be used in GIS.

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CHAPTER 2

LITERATURE AND CASE REVIEW

2.1 Benefits and Impact of Renewable Energy Facilities

It is widely accepted that Renewable Energy (RE) is a safe and clean energy source. Its contribution on climate change mitigation makes RE one of the most important energy source alternatives in a number of countries. However, along with increasing size and number of RE facilities, impacts also exist. In the following sections, benefits and impact of RE in existing literatures will be discussed. Specifically, the relationship between RE and landscape will be addressed. Literature on visual impact of wind turbines will be further examined.

2.1.1 Benefits of Renewable Energy Facilities

Rio (2008) pointed out that RE's sustainability benefits are composed of socio-economic and environmental benefits. Numerous studies have addressed on the later benefits, however, studies on socioeconomic benefits are lacking, including diversification and security of the energy supply, enhanced regional and rural development opportunities among others.

- Environmental benefits include mitigation of acid rain, stratospheric ozone depletion, and greenhouse effect (Dincer, 2000; Midilli et al., 2006).
- Socio-economic benefits: increased energy security (Midilli et al., 2006; Rio, 2008), increase of energy-independence (Tsoutsos, 2005; Takigawa et al., 2012), poverty reduction and improved standard of living (Meier and Munasinghe, 2004), decentralized and diversification of the energy supply (Rio, 2008), enhancing rural development (Reddy et al., 2006; Lopez et al., 2007), reduction of regional income disparities (Komor and Bazilian, 2005), improve local income (Takigawa et al., 2012), job creation (Bergmann et al., 2006; Hillebrand et al., 2006).

2.1.2 Impact of Renewable Energy Facilities

There are many kinds of Renewable Energy Sources (RES), such as: solar power, wind power, biomass, and hydro-power. The impacts depend on the type of RE technology considered. Therefore, the impact is discussed based on different types of RE technologies as follows.

- **Solar (Photovoltaic)**

Tsoutsos (2005) discussed the impact according to three types of solar energy technology. They are: solar thermal heating, photovoltaic power generation, solar thermal electricity. All the types of solar energy technology have common issues with the environment. They are land use, visual impact, and impact on ecosystems issues. See details in the following Table 1.

Table 1. Solar energy technologies' negative impacts (Source: Tsoutsos, 2005)

Impacts–burdens	**Alleviation technologies/techniques**
Solar thermal heating	
Visual impact on buildings' aesthetics	Adoption of standards and regulations for environmentally friendly design; Good installation practices; Improved integration of solar systems in buildings; Avoid viewable solar panels on buildings of historic interest or in conservation areas.
Routine & accidental release of chemicals	Recycling of used chemicals; Good practices—appropriate disposal.
Land use	Proper siting and design.
Photovoltaic power generation	
Land use: large areas are required for central systems. Reduction of cultivable land	Use in isolated and deserted areas; Avoidance of ecologically and archeologically sensitive areas; Integration in large commercial buildings (facades, roofs); Use as sound isolation in highways or near hospitals.
Visual intrusion—aesthetics	Careful design of systems; Integration in buildings as architectural elements; Use of panels in modern architecture instead of mirrors onto the building facade
Impact on ecosystems (applicable to large PV schemes).	Avoidance of sensitive ecosystems, areas of natural beauty, and archaeo logical sites.
Use of toxic and flammable materials (during construction of the modules).	Avoidance of release of potentially toxic and hazardous materials with the adoption of existing safety regulations and good practice.
Slight health risks from manufacture, use, & disposal	Good working practices (use of protecting gloves, sunglasses, and clothing during construction).

Solar thermal electricity	
Construction activities	Good working practices; Site restoration; Avoidance of sensitive ecosystems and areas of natural beauty.
Visual impact—aesthetics	Proper siting (avoidance of sensitive ecosystems and areas of natural beauty, densely populated areas).
Land use	Proper siting.
Effect on the ecosystem, flora and fauna (especially birds)	Proper siting (avoidance of sensitive ecosystems).
Impact on water resources water use (for cooling of steam plant) and, possibly, water pollution due to thermal discharges or accidental discharges of chemicals used by the system	Appropriate constraints (not the excessive use of existing resources); Improved technology (use of air as heat-transfer medium); Exploitation of the warm water in the nearest industry in the production stream. Good operating practices and compliance with existing safety regulations; Employees should be educated and familiarized with the systems.
Safety issues (occupational hazards)	--

- **Wind power**

Wind power does not emanate greenhouse gases, consume fossil energy, or cause energy safety issues with radioactive waste. Therefore, it has been considered as environmentally friendly energy source. However, it still imposes some impacts on human-life. According to Leung and Yang (2012), the main impacts include: noise, visual impact, effect on animals and birds, and climate change. Other impacts have also been indicated in the literature, such as: electromagnetic interference (Coles and Taylor, 1993), flora (Australian wind community, 2006), shadow flickering (Australian wind community, 2006; Katsaprakakis, 2012; Danish wind association, 2014), occupation of land (Katsaprakakis, 2012), waste water and solid waste (Bao and Fang, 2013). Various studies show that visual impact is one of the main impacts of wind farms, and the leading cause of public opposition (Thayer and Freeman, 1987; Wolsink, 2000, 2007; Kaldellis, 2005).

China doubled its wind power capacity in 2009, and it still maintains its position as a global wind power leader in cumulative terms with a total of 75.32 GW (Global Wind Energy Council, 2012). Along with economic increase and urbanization, many big size wind farms have been built up in China. Bao and Fang (2013) pointed out that, “some of these impacts may seem minor at present, but the potential long-term effects are not yet known”.

- **Biomass**

Bao and Fang (2013) stated that although biomass energy is considered carbon neutral energy source, environmental impact may be found in the incomplete combustion and inefficient energy production. The environmental impacts of biomass energy include: emission of harmful gases by improper management, depletion of nutrients, topsoil erosion, soil salinization, water pollution due to fertilizer, and local pesticide runoff.

- **Hydro-power**

The use of hydropower has a long history in human civilization. Water is fundamental for many human needs; for drinking, for food, for energy production and for health (Omer, 2008). Although hydropower is also marked as green energy, the construction and operating of the power plants have negative impacts on the environment too, such as affecting land use, residential areas, and natural habitats in dam areas by submergence (Bao and Fang, 2013). The submergence may cause loss of bio-diversity, harm fish populations, cause great changes in natural flow regimes, and slopes destabilization and climatic alterations (Ranganathan, 1997; Sperling, 2012). Furthermore, some CO_2 are still produced during the construction and operating process of hydro power plant.

- **Geothermal**

Raybach (2003) has identified several environmental impacts of geothermal power plants. They are changes to landscape, land use; emissions into the atmosphere; surface and subsurface water changes; noise; land subsidence, seismicity, and solid waste. Similarly, Iceland researcher Kristmannsdóttir and Ármannsson (2003) identified the impacts as: surface disturbances; physical effects of fluid withdrawal; noise; thermal effects; chemical pollution; biological effects; and protection of natural features. They also pointed out that scenery issues also need to be addressed in places of outstanding beauty, touristic and historical areas.

2.1.3 Renewable Energy Facilities and Landscape

The transition from a fossil fuel society to a sustainable energy supply society is one of the important concepts in climate change mitigation. Market projections indicate fast growth in RE installations and generation around the world. The RE facilities will be located in the built environment near users and consumers, these facilities directly change the landscape (Figure 2-3), in areas such as topography and vegetation. These spaces are usually planned and designed by landscape architects. In spite of providing a sustainable energy production approach, RE also needs to achieve a sustainable transformation from landscape perspective. The quick development of RE brings new challenges to landscape architecture filed in energy transition process.

RES is resources existing objectively in the physical environment, us human beings, to percept, to use these resources using our intelligence, such as technology and planning tools (Figure 4). Mitani (1990) described the relationship between modern technology and human beings in the following paraphrase. “The landscape of this century is gradually changing with new technology. The belief in science and technology forms new hope for modern human beings, on behalf of religion and philosophy. People start to understand nature through science and technology. Science and technology sometimes are understood as being irreconcilable conflict against nature, sometimes they are understood as an element of human intellect produces developed from nature.”

Figure 2. Palm spring wind turbines. (Source: by Tom Grubee. http://www.tomgrubbe.com/)

Figure 3. Solar farm in Ivanpah Valley, C.A. USA. (Source: Google earth)

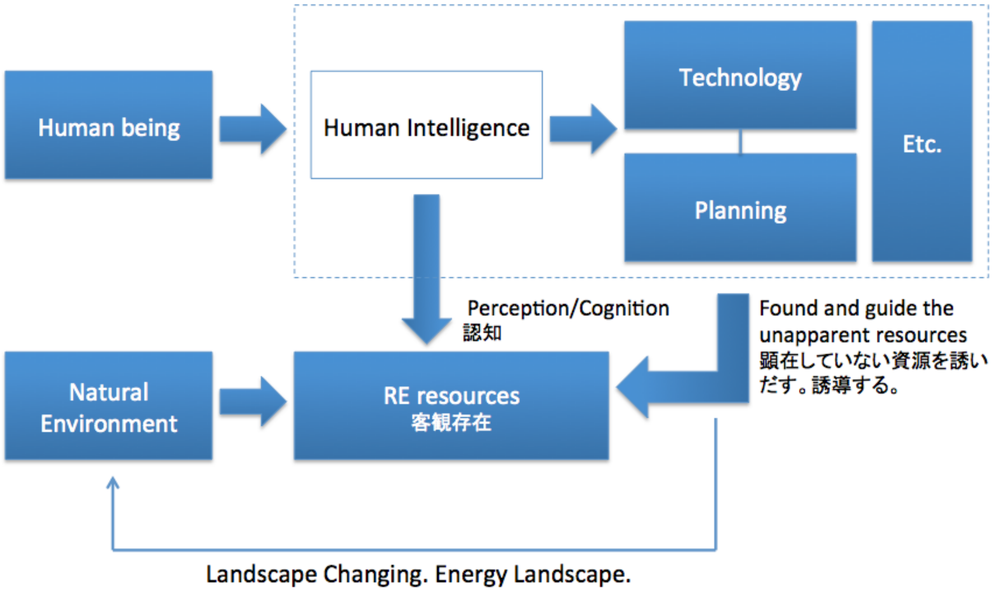

Figure 4. Relationship between technology, planning, and RE resources. (Source: by Author).

However, the research and practice in landscape and RE cross-field were only noticed recently. Landscape architecture, as discipline, deals with tasks such as land use, ecological systems, residence, historic, cultural and aesthetic aspects of these. As mentioned in Section 2.1.1 and 2.1.2, to solve or mitigate impacts of different RE technologies, landscape architecture can contribute to help solving issues on environmental and aesthetic aspect, thus provide the sustainable implementation of RE technologies. Stremke (2012) proposed the concept of “sustainable energy landscape". The concept was defined as "physical environments that can evolve on the basis of locally available renewable energy sources without compromising landscape quality, biodiversity, food production and other life-supporting ecosystem services". The change of current fossil fuel energy structure into sustainable energy structure may take centuries, to accelerate the transition, innovative and systematic spatial planning and design approaches are necessary. According to Stremke (2009), at Wageningen University, Netherlands. They have proposed a five-step approach to support identifying strategies for energy-conscious transformation at regional level. The process is 1) inventory and analysis of the case-study region; 2) studying existing context scenario; 3) map of possible future developments in case-study region; 4) visions for a sustainable energy landscape composition under conditions provided context scenarios; 5) create strategies for energy-conscious transformation that can be identified through comparative analysis of all visions. Through application of this approach at the regional scale, he argued that "sustainable energy transition may support realization of added values such as preservation of cultural landscapes and climate change adaptation (Etteger and Stremke, 2007)". See Figure 5 for a sample of spatial energy vision in region of Southeast Drenthe, the Netherlands (Vandevyvere and Stremke, 2012).

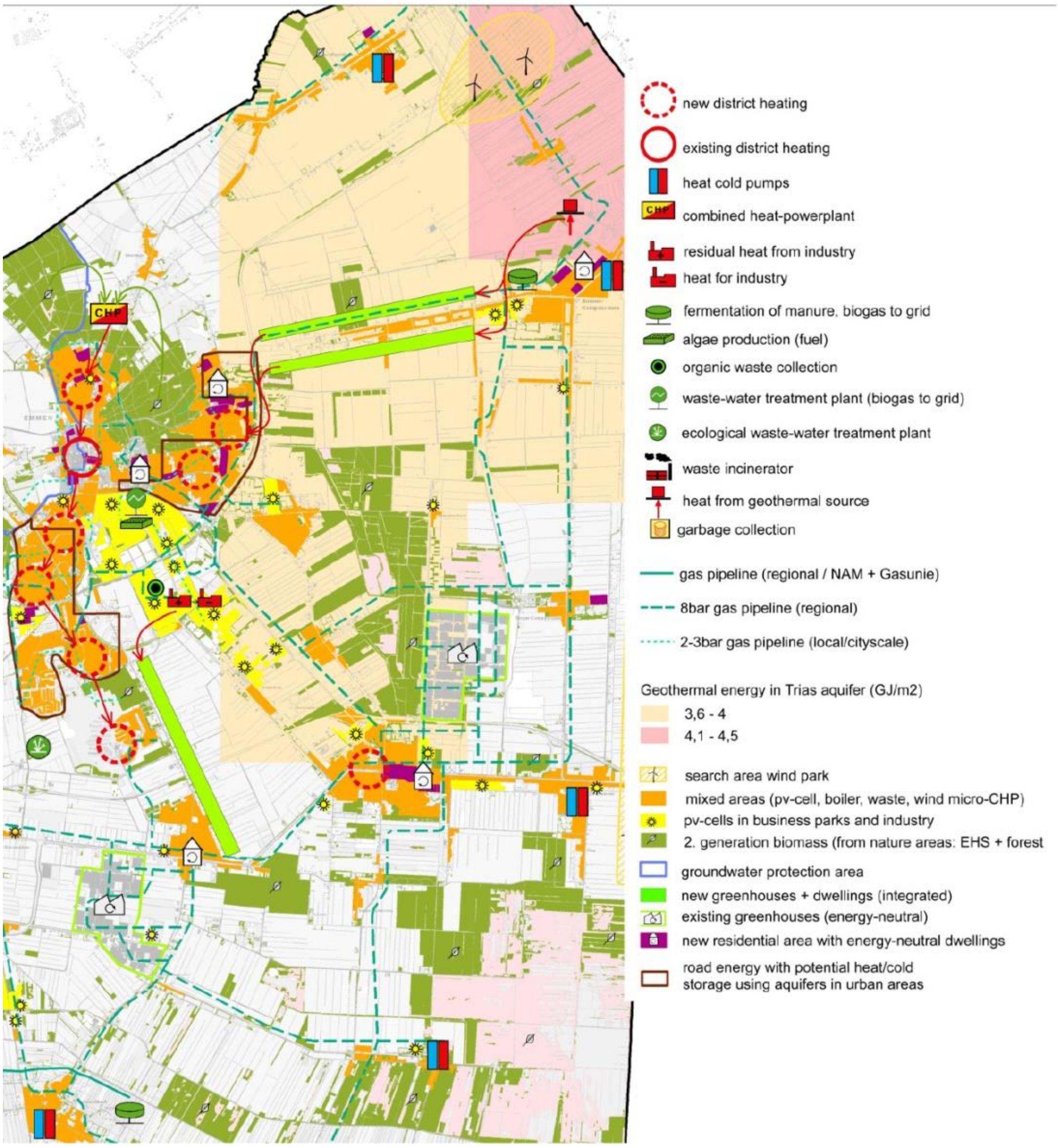

Figure 5. A sample of spatial energy vision in region of Southeast Drenthe, the Netherlands.

(Source: Vandevyvere and Stremke, 2012).

2.1.4 Visual Impact of Wind Turbine

As the environmental problems, such as air pollution, greenhouse effect, we are facing get more serious day by day, extensive effort has been made to shift our energy sources from those traditional energy sources such as: coal, oil and fossil fuel to clean renewable energy. RES includes wind, solar, water power and so on. Nowadays, these new energy sources play an important and increasing role in current world's energy mix.

Among which, wind energy is developing in a very fast speed in the last decade. From 2008-2009, 38,312MW were added and shown a growth rate of 31.7%, reached the total capacity of 159,213MW by the end of 2009, according to the prediction, total number will reach 203,500MW by the end of 2010 along with the high increase rate in 28.3% (Figure 6). As the trend continues that wind energy capacity doubles every three years, wind energy will become one of the popular energy resources in the future.

Although wind energy can be considered as the cleanest energy (Figure 7), accompany with the construction of wind farm project, there are also a lot of negative impacts exists, such as: impact on birds, landscape, and noise problems. Among all the impacts, visual impact of wind farms on landscape is the hardest impact to be aware of and objectively evaluated. A unique challenge has been put in front of landscape architecture professional field.

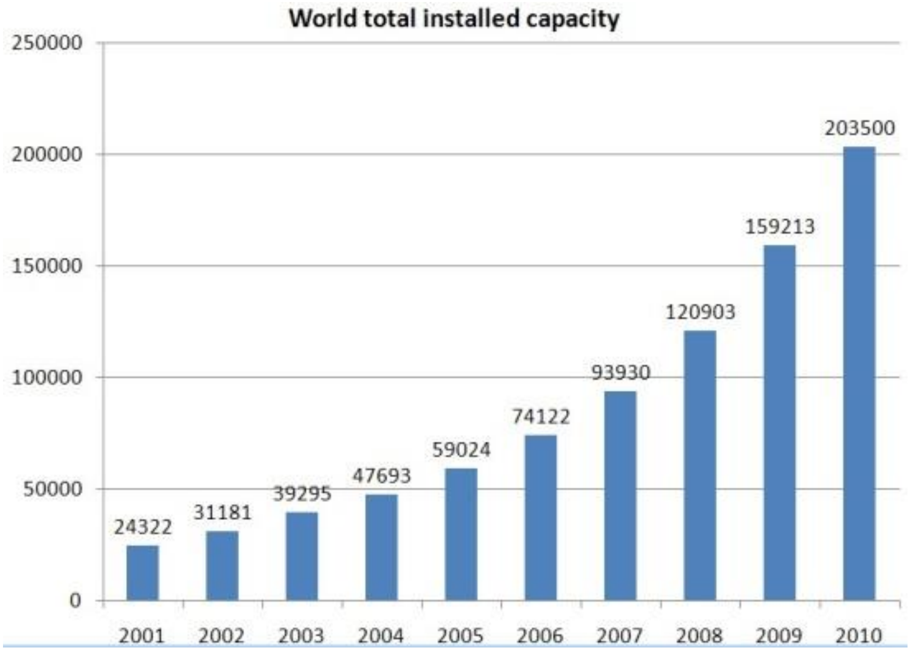

Figure 6. World total installed capacity. (Source: Global wind energy council, 2009)

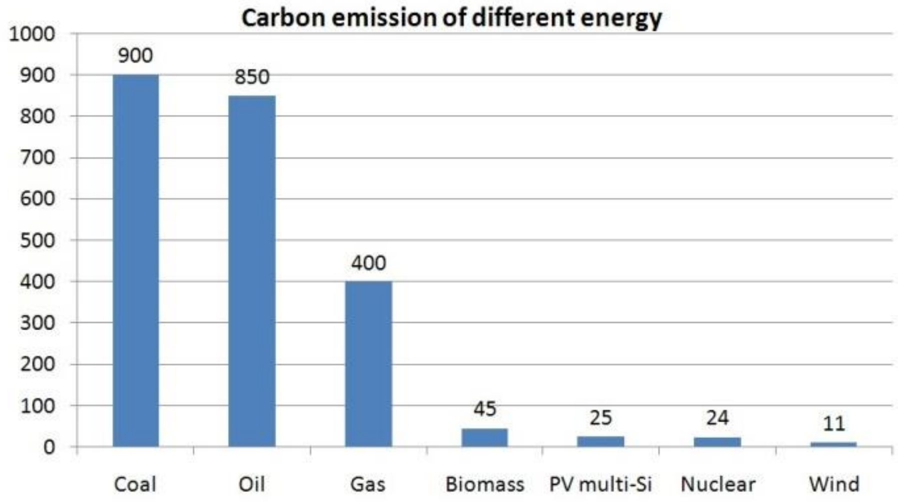

Figure 7. Wind energy has the lowest carbon (CO_2) emission in all the energy forms.

(Source: Bouton, 2009)

As the development of wind engineering, wind turbines are getting bigger and bigger, which means wind turbines will get more and more apparent in the landscape day by day, and no need to mention the increasing number of them. Although public opinion surveys show a strong support for wind energy development around the world, surveys done by Thayer (1987), Wolsink (2000, 2007), and Wustenhagen et al. (2007) show a tendency that once a project area proposed and the impacts become more apparent, people will become less supportive to their favoring wind energy. According to research by Wolsink (1989), the real root cause of opposition is visual impact and it is hard to be aware of.

"*People unconsciously realize that opposition on aesthetic grounds is subjective, and is, therefore, often dismissed by public officials. They then rationalize their opposition by citing concerns such as noise, shadow flicker, and birds, which can be objectively evaluated. But visual impact remains the root cause of opposition*" (Wolsink, 1989).

Within all impacts, visual impact on landscape is the most difficult item to be noticed and evaluated objectively. Unlike noise and topography changes, visual impact cannot be objectively surveyed and revealed by specific data. Furthermore, visual impact is different due to people different perceiving and tolerance. Wind farms pose a unique challenge in protecting visual resource values in settings from rural to urban. Planning, locating, and designing these wind facilities so that they fit into local landscape is both an art and science task and it is also represents an expanding field of opportunity for the landscape architecture profession.

By the end of 2009, Japan has ranked in 13th in the world with the total wind energy capacity of 2.056 MW (World Wind Energy Report, 2009). Recently, in Japan, a discussion about visual impact of wind turbines in high landscape value area such as National parks has started by Japanese Ministry of Environment. However, seldom attentions have been paid to visual impact to those suburban settlements in Japan. After The Great North Eastern Japan earthquake on March 11, 2011 and the consequent nuclear disaster, the Japanese government is making efforts to expand installation and use of green, safe RE. Among all the RES, wind energy has the highest potential at 1,900MkW out of the total RE potential of 2,081MkW (Japanese Ministry of Environment, 2011a). Wind energy may become a popular energy source for local use in the coming few decades. It may also play a vital role in post-earthquake reconstruction in Japan.

However, an increase in size and number of wind turbines increases the visual impact to the landscape too. Various studies show that visual impact is one of the main impacts of wind farms, and the leading cause of public opposition (Kaldellis, 2005; Thayer and Freeman, 1987; Wolsink, 2000, 2007). In Japan, most of the studies have focused on perception research (Ohgishi et al., 2006; Sakamoto et al., 2004). A “Technical Guideline for wind energy facilities in high scenic areas” was developed by Japanese Ministry of Environment (2011b). This was based on their work on visual impact of wind turbines in high scenic areas such as National Parks since year 2005. High scenic areas have received more attention than local areas in Japan. Local areas require attention too, as they are perceived daily by the residents due to proximity to their living quarters.

Although visual impact is difficult to evaluate objectively, some applications and regional assessments have been accomplished (Bioshop and Miller, 2007; Lothian, 2007; Moller, 2006). Bioshop and Miller (2007) finished the assessment of visual impact of off-shore wind farms and identified the visual threshold for detection, recognition and visual impact under different landscape settings. Lothian (2007) accomplished landscape quality assessment in Australia. Moller (2006) proposed a method to reflect the change of visual impact of wind farms by means of Geographic Information System (GIS) in regional scale.

Several assessment methods have been developed for different levels, such as GIS-based assessment, Multi-criteria Analysis, and Spanish Method. However, there is lack of integrated visual impact evaluation methods at both city and community levels. GIS-based assessment is suitable for regional or city level evaluation. It can be overlaid with visual condition analysis, land use, and population analysis among others. Multi-criteria analysis is now widely used to analyze multiple elements of target sites, such as physical attributes (landscape form, topography and land use) and aesthetic attributes, such as color and texture among others (Leung and Yang, 2012). However, it is not specialized for settlement level evaluation, and its factors can be decided based on the target site making it difficult to ascertain the reliability of factor selection and evaluation. Spanish Method (Hurtado et al., 2004) was developed for local level evaluation, aiming to assess a wind farm's visual impact to a target settlement. A scoring 'Visual Impact Evaluation Matrix' including five coefficients was proposed. Its only empirical application was carried out in Crete Island in Greece (Tsoutsos et al. 2009).

2.2 Renewable Energy and GIS

2.2.1 Development of GIS Technique

In the 1950s', the concept of GIS has been proposed. Along with the development of computer technology, the first computer-based GIS was established by a Canadian in 1960s'. During the period of 1970s', the computer technology rapidly developed, this made GIS technology starts to get more attention and potential to further develop. The concept and technology of GIS became popular and started to be widespread in the 1980s'. In 1990s', GIS has been used all over the world, and it became the most useful tool and assistant in lots of fields.

Regard to the application of GIS technology in RE field, there are two main topics that have been studied a lot. First is evaluation of RE potential, and the second is GIS-based planning methodology and approach for RE planning. GIS have proved to be a useful tool for regional RE potential estimation (Hoesen and Letendre, 2010; Arnette and Zebel, 2011; Gil et al. 2011) and support for decision making in energy planning (Clarke and Grant, 1996; Voivontas et al., 1998; Domingues and Amador, 2007). 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. In 1996, the earliest paper that focusing on biomass energy potential assessment has been published. This study (Graham et al., 1996) proposed a modeling system for potential cost and supplies evaluation of biomass energy from biomass crops at regional level. After this, several studies (Voivontas et al., 1998; Yue and Wang, 2006; Ramachandra and Shruthi, 2007; Arnette and Zebel, 2011) that focusing on one or multiple RES potential evaluation has been also published.

Recently, the visualization function and data analysis ability of GIS has been greatly developed. The update of ArcGIS from 9.0 to 10.0 made its visualization ability and analysis toolbox updated, such as ArcScene. Furthermore, the software has been designed more easily to learn and use. Besides ArcGIS, other GIS software, such as Grass GIS, Map GIS, is now be used by many users. These software widen and complete the function of GIS. The different features of these GIS software provide different options for users, so that they can choose the most appropriate software according to their specific purposes.

Along with the development with Internet technology, web-based GIS is becoming popular for its information sharing and online interactive ability. It also provides a platform for planning participation (Simao et al., 2009; Bayern Gov., 2014). In Japan, many municipalities, such as Shizuoka Pref. (Figure 9), Fukushima Pref., have used online Forest GIS. The online forest GIS shares information on forest type, age, management condition, forest road, protected forest area, topography, and forest recreation areas etc.

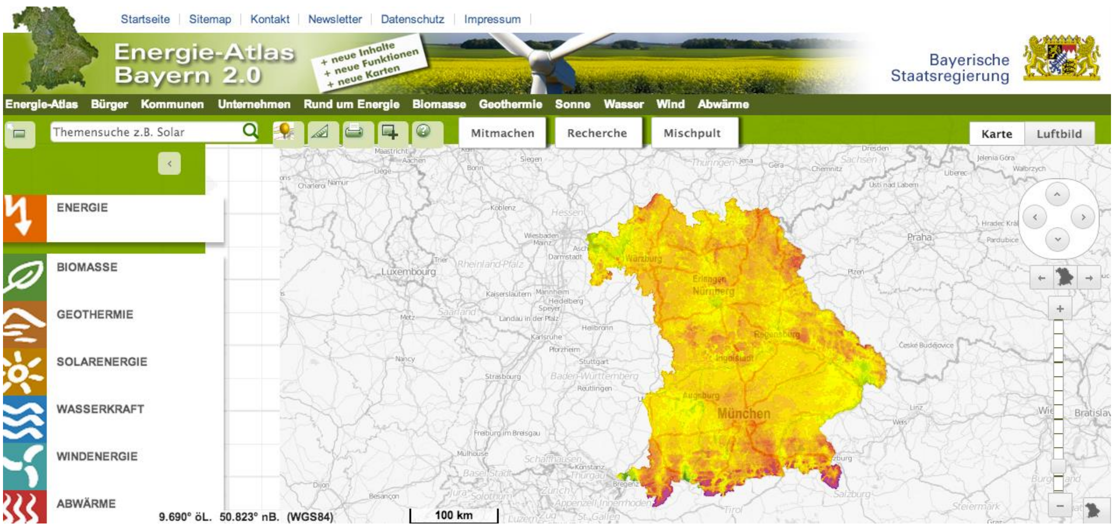

Figure 8. Energy-Atlas Bayern with showing wind potential at 80m.

(Source: Bayern Gov., 2014)

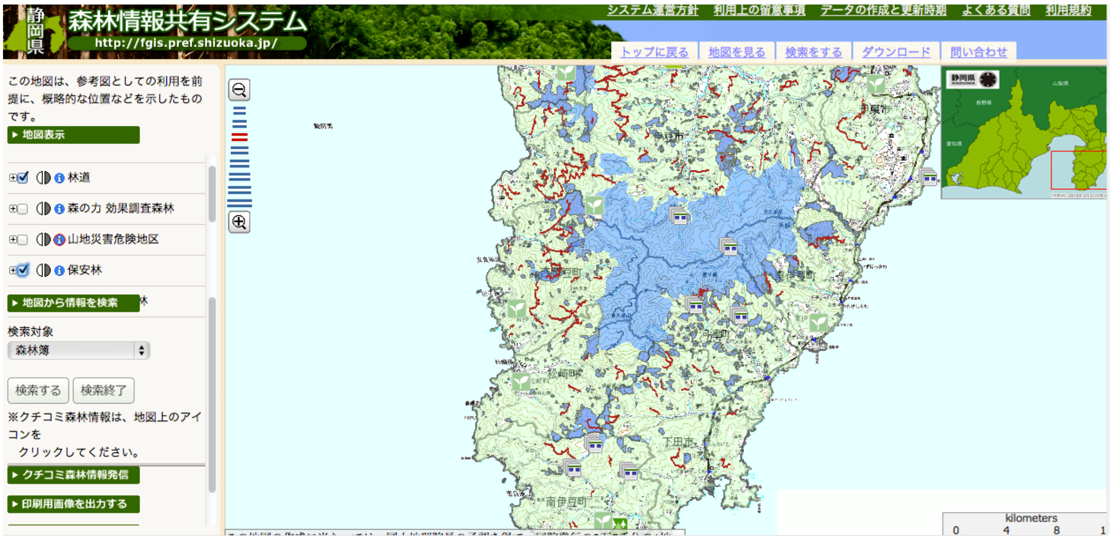

Figure 9. Shizuoka Forest GIS with showing forest road and protected forest area.

(Source: Shizuoka Gov., 2013)

2.2.2 GIS-based Planning of Renewable Energy: Steps, Structure

In order to find references for RE planning approach that will be proposed in this study, previous literature was read with respect. Some important studies are briefly described as follows.

Voivontas et al. (1998) proposed a RES-Decision Support System (RES-DSS). The proposed system is composed of RE potential evaluation and economic analysis (levelised electricity cost and Internal Rate of Return analysis). Regard to potential evaluation, this study proposed the concept of “theoretical potential”, “available potential”, and “technological potential”. After overlay with environmental, social, and wind turbine technical criteria, the available potential and technological potential can be clarified based on theoretical potential using GIS. See Figure 10.

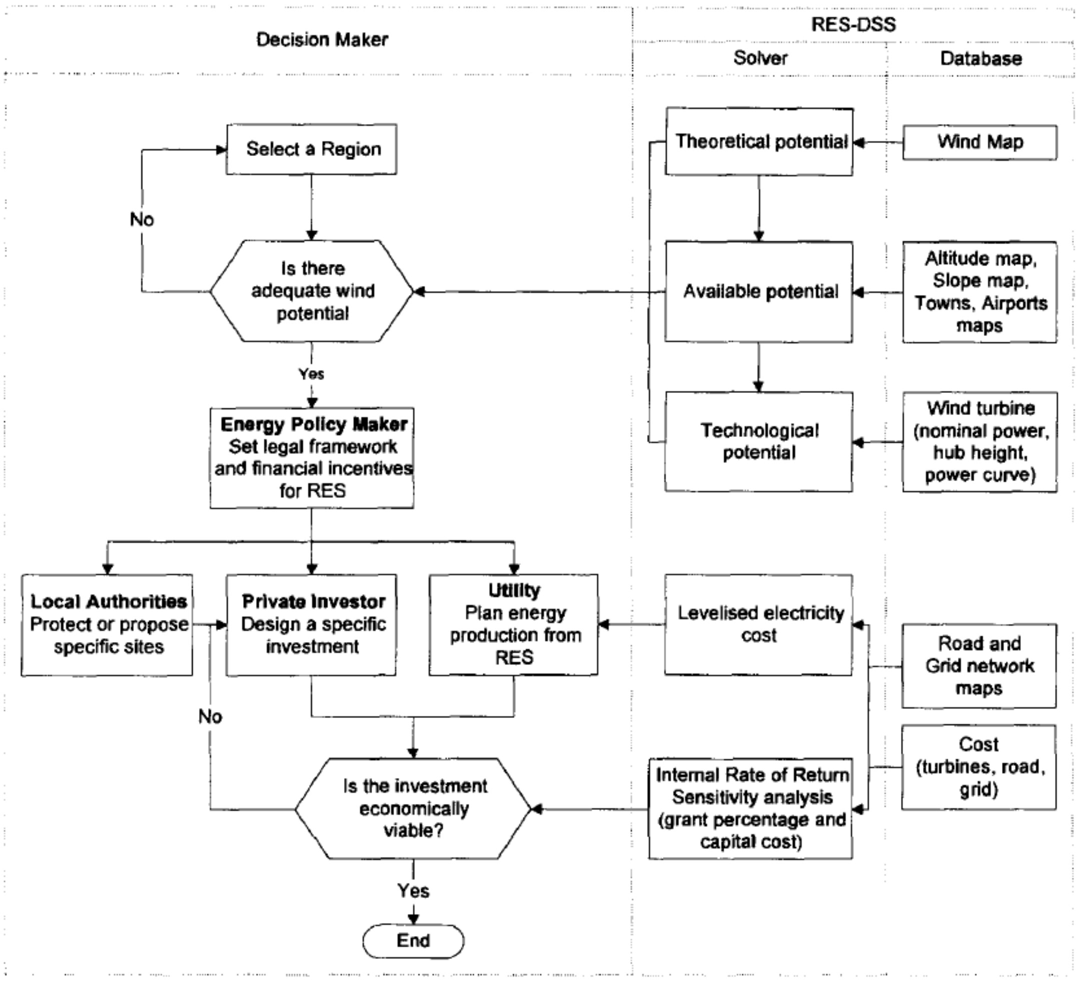

Figure 10. Renewable Energy Source-Decision Support System. (Source: Voivontas et al., 1998)

Muselli et al. (1999) proposed a computer-aided approach to analyze integration of RE systems for remote areas using GIS. The approach is composed of three main steps. First, to prepare maps, second to establish regional database based on maps, third to finalize regional planning of RE. Within the third step, it includes electricity production cost, optional systems for each site (system sizing), and technical and economical analysis for local suppliers.

In the same year, Sarafidis et al (1999) proposed an approach for regional planning to promote the RE. They mainly pointed out that "energy representations are still highly aggregated and do not examine possible variations in the spatial distribution of energy demand and of the energy supply sources". In order to integrate RES into the energy system, the scale of energy analysis and planning should be shifted from the national to regional and local level. Their approach is composed of two parts. First, to estimate energy demand, where useful energy demand and final energy consumption estimation. Second, to estimate of RES potential, they finalized potential estimation for wind biomass, solar and hydropower.

Based on GIS, Amdor and Dominguez (2005) developed a decision making process for electrification in rural area with RES. The process includes energy consumption analysis, with socio-economical, technical, and geographic data, as well as levelised electricity cost (LEC) calculation, the potential for different RE technology can be identified. They argued, " Correct consideration of the energy consumption is fundamental". See Figure 11.

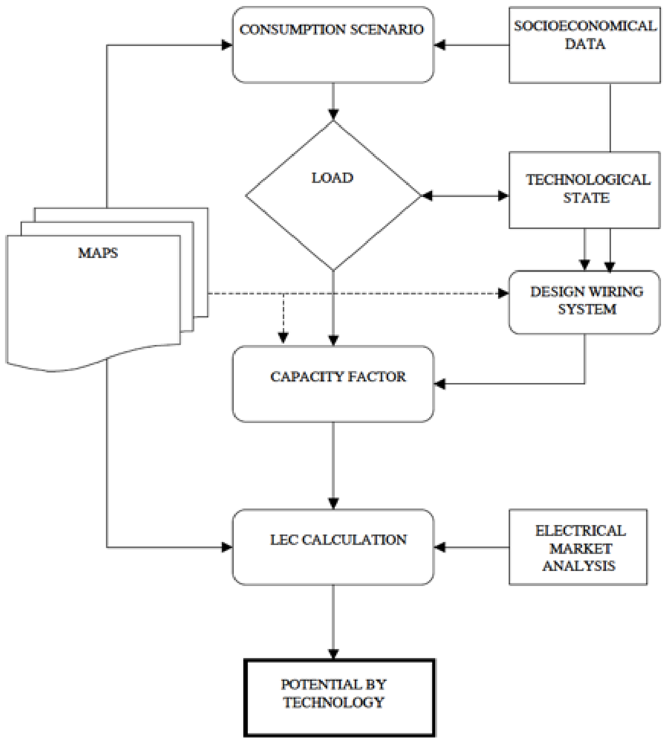

Figure 11. The decision making process for electrification in rural area with RES.

(Source: Amdor and Dominguez, 2005).

Yue and Wang (2006) finalized a GIS-based evaluation of multifarious RES at local level in Chigu area, Taiwan. After 1) RES potential evaluation, 2) scenario, and 3) economic analysis, they discussed 4) environmental benefits and impacts for each RE technology, as well as suggestions for 5) political implications.

Terrados et al (2009) proposed a combined methodology for RE planning. They reviewed existing approaches for RE planning at regional level first, and based on review, they proposed a combined methodology using Multi-criteria Decision Technique (MDCA), Delphi techniques (expert opinion), and SWOT analysis (Strength-Weakness-Opportunity-Threats). They applied the approach to a Spanish region. See Figure 12.

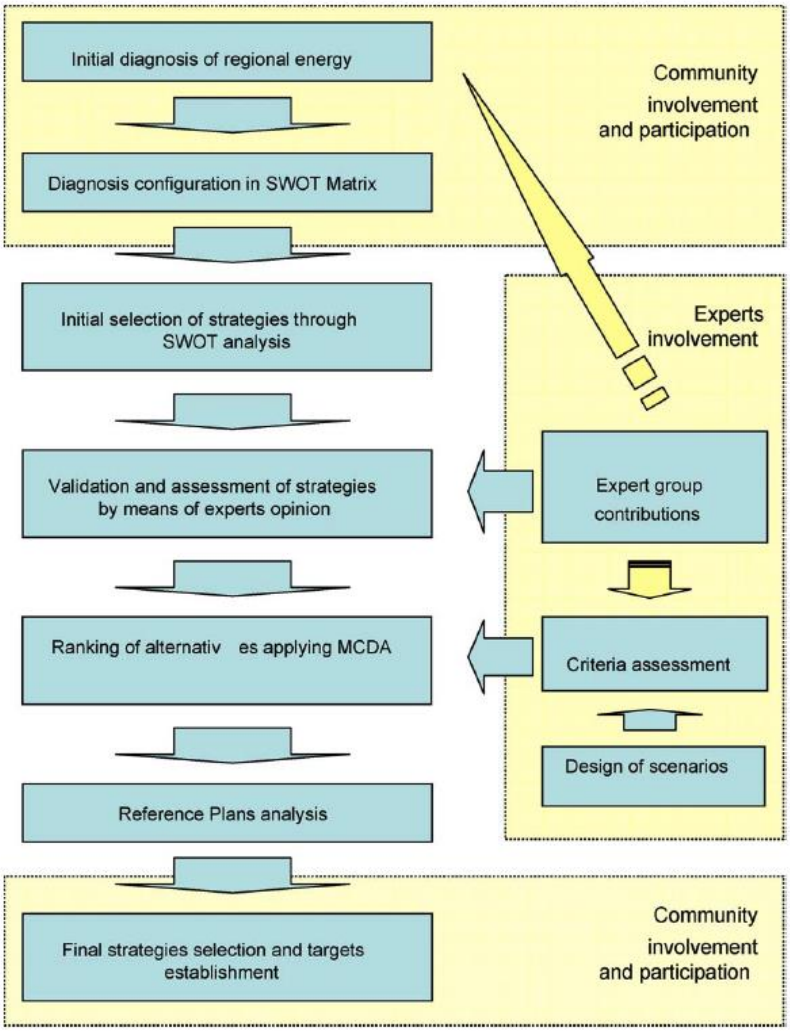

Figure 12. A combined methodology for RE planning at regional level.

(Source: Terrados et al., 2009)

Based on literature review, it has been found out that energy planning of RE usually compose of several parts. They are as follows.

1) Energy consumption evaluation,

2) RE potential evaluation: theoretical potential, available potential evaluation,

3) Socio-economical analysis,

4) RE benefits and impacts analysis, and

5) Scenario analysis.

Overall, the existing methodologies and studies on RE planning has focused on estimation (Voivontas et al., 1998; Yue and Wang, 2006; Hoesen and Letendre, 2010; Gil et al., 2011; Arnette and Zebel, 2011) and mapping (Ramachandra and Shruthi, 2007), whereas energy self-sufficiency analysis based on demand-supply prediction at the regional level has been lacking. 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.

2.2.3 Methods and Criterions: GIS-based Site Selection and Potential Evaluation

In RE potential survey report, Japan Ministry of Environment (2011) used the following (Figure 13) methodology to estimate RE potential at national level. First, RE abundance was estimated then overlaid with social and nature criteria, the available RE was estimated. Finally, based on different economic condition, scenario analysis was finalized and compared.

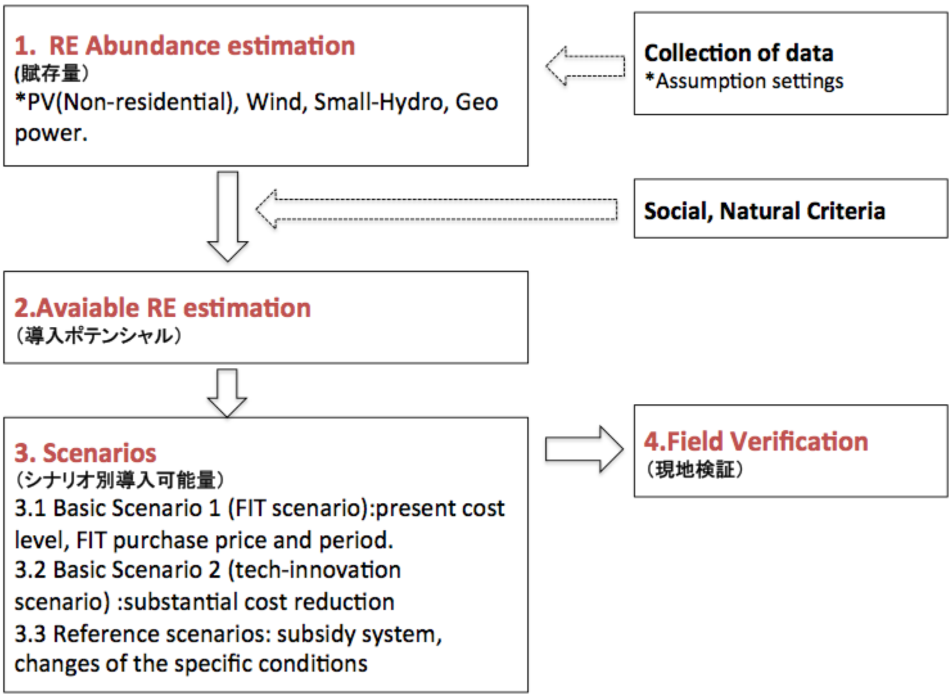

Figure 13. Evaluation process of RE potential report 2011.

(Source: based on Japanese Ministry of Environment, 2011. By author.)

Schaffhausen developed their municipal energy planning (including RE) in 2007 (Figure 14). Within which, energy consumption analysis, RE potential analysis, waste heat analysis was done. The main feature is this plan combining residential housing plan and industrial plan with energy plan. The methodology to develop the energy plan is shown in Figure 15. The plan making procedure is clarified based on on-site interview and e-mail interview with Schaffhausen's city officer. See more detail in Appendix 1.

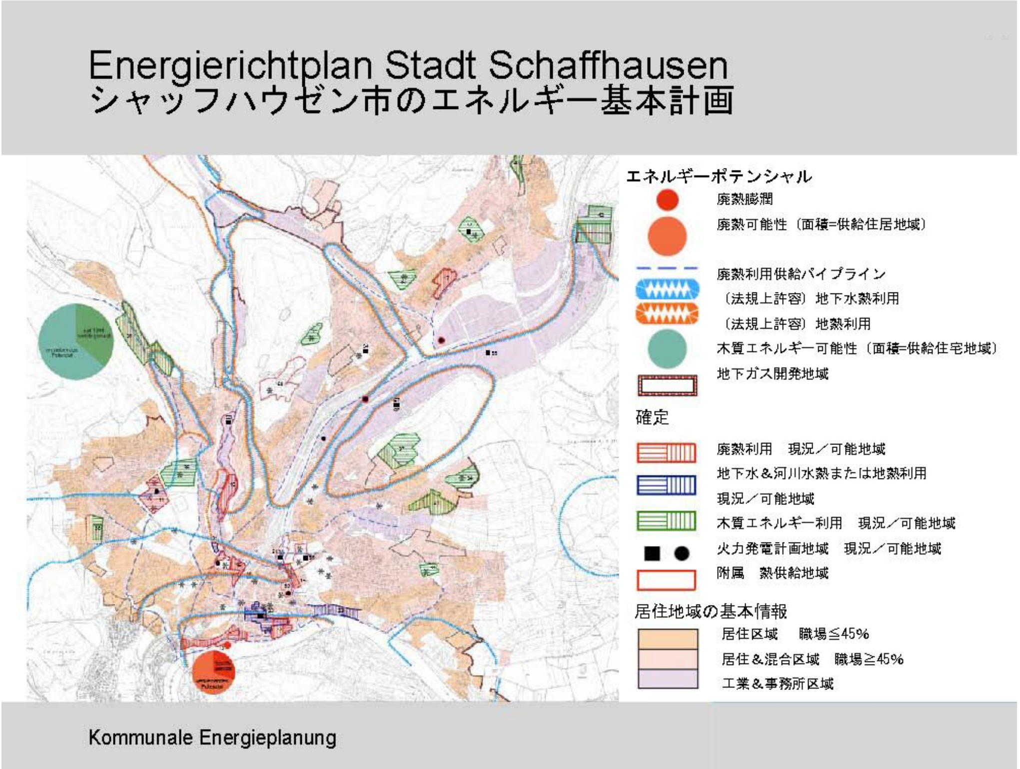

Figure 14. Energy plan of Schaffhausen, Switzerland.

(Source: http://www.stadtschaffhausen.ch/. Translation: Isami Kinoshita)

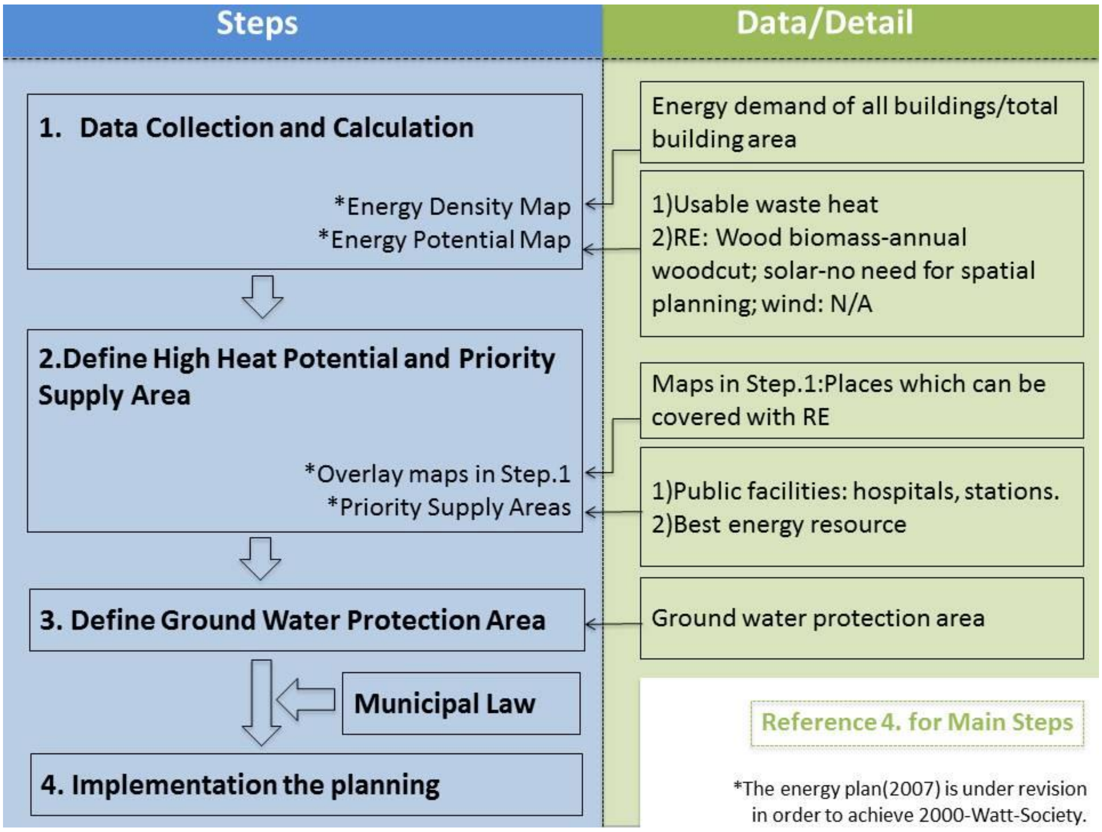

Figure 15. RE planning procedure developed and used by Schaffhausen, Switzerland.

(Source: by author. Based on onsite and e-mail interview).

Based on literature review, the criteria for wind turbine site selection, PV potential estimation and mega-solar farm site selection, available forest and agriculture, and distance for biomass power plant have been summarized. See Table 2-4.

Table 2. Criteria for wind turbine site selection.

Study	Wind speed (m/s)	Altitude (m)	Slope	Distance (m)					
				City, town	Village	Water body	Ecological area	Airport	Historical area
Sarafidis et al.,1999	>6	<1000	<70%	>1000	-	-	-	-	>1000
Voivontas et al.,1998	>6	<1000	<60%	>1000				>2500	>2000
Arnette and Zebel, 2011	-	-	<20%	>500		>500	>1000	>2000	-
Yue and Wang, 2006	>4	-	-	>500	>250	-	>250	-	-
Hoesen and Letendre, 2010	-	600-1050	<60°	-	-	-	-	-	-
Japanese Ministry of Environment, 2011	>5.5	<1000	<20°	>500	>500	-	-	-	-
Baban and Parry, 2001	>5	-	<10%	>2000	>500	>400	>1000	-	>1000
Silz-Szkliniarz and Vogt, 2011	-	<2000	<25°	-	>500	>250	>500m	>3000	>1000

Table 3. Criteria for photovoltaic (PV) potential estimation on rooftops and Mega-solar farm site selection.

Study	Potential estimation on rooftops	Mega-solar farm		
		Slope	Direction	Area
Yue and Wang, 2006; Hoesen and Letendre, 2010.	Total rooftops area*25%	-	-	-
Arnett and Zebel, 2011	-	0-2.5%	Any direction	-
		2.5-15%	South-facing direction	
Fukushima Gov., 2013	-	-	-	>1.5ha

Table 4. Criteria for available forest and agriculture resources, distance for biomass power plant.

Study	Slope	Agricultural residue	Distance
Hoesen and Letendre, 2010; Vettorato et al.,2011.	<20%	-	-
Vettorato et al.,2011	-	-	2000m
Yue and Wang, 2006; Hoesen and Letendre, 2010.	-	Total energy crop area*50%	-

2.3 Renewable Energy and Spatial Planning

2.3.1 Spatial Planning: Definition, Characteristics, Theory

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 (Federal Ministry of Transport, Building ad Urban Development, 2013). It usually embraces land use planning and relevant public policy. In one of the earliest descriptions 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) (CEMAT, 1983).

Healey (1997) 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 (1997) 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 (1998) 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 (2001) indicated that spatial planning identifies medium and long-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. (2006) 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.

2.3.2 Spatial Planning for Renewable Energy

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.

A comprehensive spatial planning system has not been established in Japan yet. According to Kinoshita (2011), impacts from political intervention and existing policies such as the agricultural land conversion policy, result 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 point of view into land use planning.

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 (Jabareen, 2006). 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 (Bergmann et al., 2006; Rio and Burguillo, 2008) 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 (Takigawa et al., 2012). 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 (2011), 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. This study 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.

2.4 Renewable Energy and Sustainability

It is usually stated that RE contributes to sustainability by providing a sustainable approach to energy generation (Elliott, 2000; Vera and Langlois, 2007), and contributing to mitigation of the greenhouse effect in the long term (Dincer, 2000). The development of RE is also one of the crucial steps for future sustainable development of energy resources. In order to promote RE, there are several studies discussing the key or driving factors leading to RE’s successful promotion (Izutsu, Takano, et al., 2012). After RE has been promoted in an area, its supply and use plays a key role in the local sustainable strategy, and it represents a crucial part of the overall strategy for sustainable development at the local level (European Renewable Energy Council, 2012). The existing literature on RE's mention that it can contribute to local sustainable development by providing various environmental and socio-economic benefits. These benefits include CO_2 reduction, employment creation and enhancement of local development opportunities among others. However, much emphasis is put on the environmental benefits, while socio-economic benefits have received less attention. Worldwide, several studies have analyzed RE's environmental sustainability benefits (Reddy et al., 2006; Gosens et al., 2013; Yang et al., 2013), among other authors emphasized RE's contribution to environmental aspects (Dincer, 2000). In contrast, socio-economic benefits are usually mentioned but their analyses have been general and mostly focus on national and regional levels, while the local level has been lacking (Rio and Burguillo, 2008). There is lack of empirical evidence on RE's socio-economic effect, especially, on rural areas that are experiencing depopulation and economic decline.

2.4.1 Renewable Energy Town/Village in Japan and China

After The Great North Eastern Japan earthquake on March 11, 2011 and the consequent Fukushima nuclear crisis, the Japanese Government is making efforts to change the energy structure. As alternative energy resources, RE goes into their focus with its clean and safe characteristics. The Feed-in Tariff (FIT) of RE was announced and started in Japan in July 2012, and is expected to accelerate the RE's development in Japan. In the meantime, China doubled its wind power capacity in 2009, and it still maintains its position as a global wind power leader in cumulative terms with a total of 75.32 GW (Global Wind Energy Council, 2013). China has also become the largest hydropower and wind power producer, as well as having the highest solar water heating capacity in the world (REN21, 2013).

Rural areas with RE in Japan and China have been established recently, and there are a few successful and practical cases. As mention in Section 2.1, there is lack of empirical evidence on RE's socio-economic contribution, especially, on the rural areas that are experiencing depopulation and economic decline. Therefore, in order to conduct a preliminary study on RE's role in sustainability, two aspects of RE: key factors for its promotion and its contribution to sustainability have been taken into account in this study.

To identify key factors for successful RE promotion and its sustainability values in rural areas, this study presents two pioneer cases: Kuzumakicho in Japan, and Chongming Island in China. Each of them stands for strong RE advancement in their home country and bear specific characteristics. Instead of comparative study, this study examines the two cases as parallel case studies using literature, local plan, policy documents review, and a questionnaire sheet with SWOT approach integrated in methods. The cases only reflect limited part of RE and its implementation status in Japanese and Chinese rural areas, but it is expecting to provide lessons learned through these cases, to contribute to the future RE promotion and sustainable development in Japanese and Chinese rural areas.

2.4.2 Brief Description: Study Areas and Method.

Kuzumakicho in Japan and Chongming Island in China were selected as study areas, their locations can be seen in Figure 16. Because the RE backgrounds and basic conditions of the two cases are quite different, the two cases were examined as parallel case studies instead of a comparative study. They were selected because they are some of the most progressive RE development cases in their respective home country's rural areas. They bear specific characteristics or issues, such as: population lost and local business decline in Kuzumakicho, quick economic and energy consumption increase in Chongming Island.

Kuzumakicho is located in Iwate Prefecture in the Tohoku region of Japan, one of the three prefectures that were greatly damaged by the Great North Eastern Japan earthquake of March 11th 2011. The town covers an area of 435km^2, with a population of 7,678 in 2890 households (Kuzumakicho Gov., 2013a). It has an average annual inland wind speed of 8m/s at the height of 70m (NEDO, 2010), and a hilly topography that has 86% forest cover. This town suffered from population loss and local business decline during the 1980s. The Japanese Ministry of Internal Affairs and Communication designate it as a "Depopulated Area". Local industries include: agriculture, dairy farming, and forestry. The success of its local RE development came from the efforts started in 1998, and Kuzumakicho now has a total electricity generation of 56,910MWh from RE facilities (wind 56,000MWh, biogas 50MWh, biomass 500MWh, and solar 360MWh). Its electricity consumption in 2011 was 36,725MWh (Kuzumakicho Gov., 2013b), indicating that RE provides 155.0% of Kizumakicho's electricity consumption. See Table 5.

Chongming Island is located at the Yangtze River mouth Pacific Ocean, about 25km from downtown Shanghai. It is the third largest island in China and covers an area of 1276km^2, with a population of 691,699 (2008). The island has abundant wind resources, its average inland wind speed reaches 7m/s at the height of 50m (Yu et al., 2008), wetlands, agriculture fields, and it is famous as the weekend tourists' site for Shanghai city. It is the first Modern Ecological Island in China. Chongming Island now has a total electricity production of 432.5GWh from RE facilities (wind 430GWh, biogas 1.5GWh, and mega-solar 1.05GWh), while its electricity consumption in 2012 was 3,980GWh (Yu et al., 2009). Hence, RE is now providing only 10.9% of its electricity consumption. See Table 6.

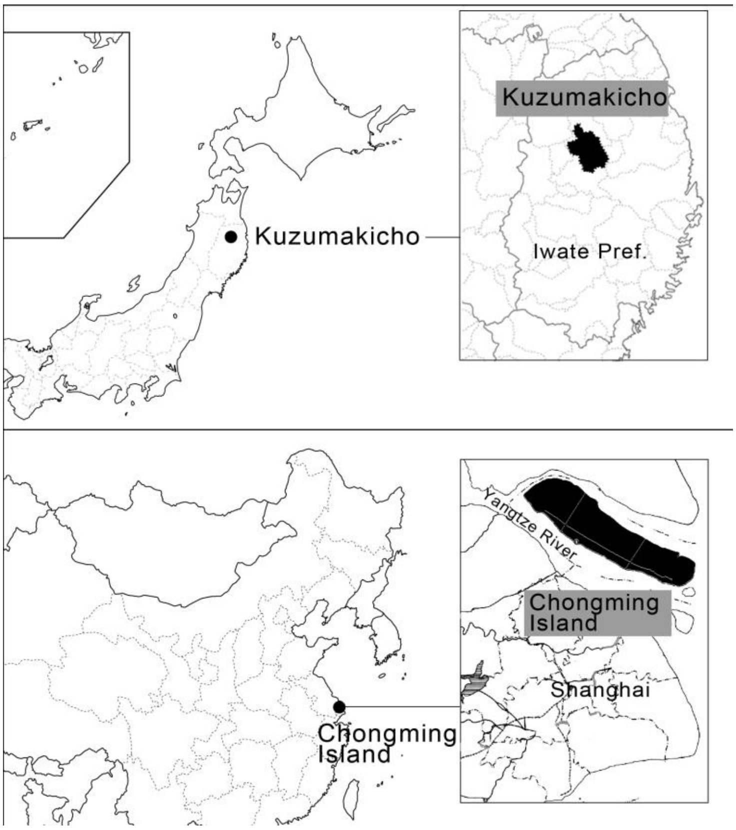

Figure 16. Location of Kuzumakicho and Chongming Island. (Source: by author)

Table 5. Current RE facilities in Kuzumakicho (Kuzumakicho Gov., 2012a)

Year	RE facility	Capacity
1998	Eco wind farm	1200kW*3
1999	Solar panel	50kW
2003	Biogas plant	Electricity: 37kW; Heat: 43,000kcal
	Pellet Boiler	500,000kcal*2
	Solar panel	20kW
	Green power wind farm	1750kW*12
2005	Biomass plant (cogeneration)	Electricity: 120kW; Heat: 230,000kcal
2008	Pellet Boiler	50kW*2
2011	Solar panel	20kW

Table 6. Current RE facilities in Chongming Island.

Year	RE facility	Capacity
2010	Mega-solar	1MW
2011	Biogas plant (Cogeneration)	380kW
2012	Wind farm	19.5MW(total)
Various	Solar thermal	140MW (Total installation area 200,000m^2)

Regarding case study methodology, in order to make the case as reflective as possible from various viewpoints, information from various data resources was included. Two approaches were used: review approach and questionnaire sheet approach, to investigate the cases. Review materials include existing literature and local policy, planning documents and reports. The questionnaire was designed with SWOT approach integrated in. The framework of the methodology is shown in Figure 17.

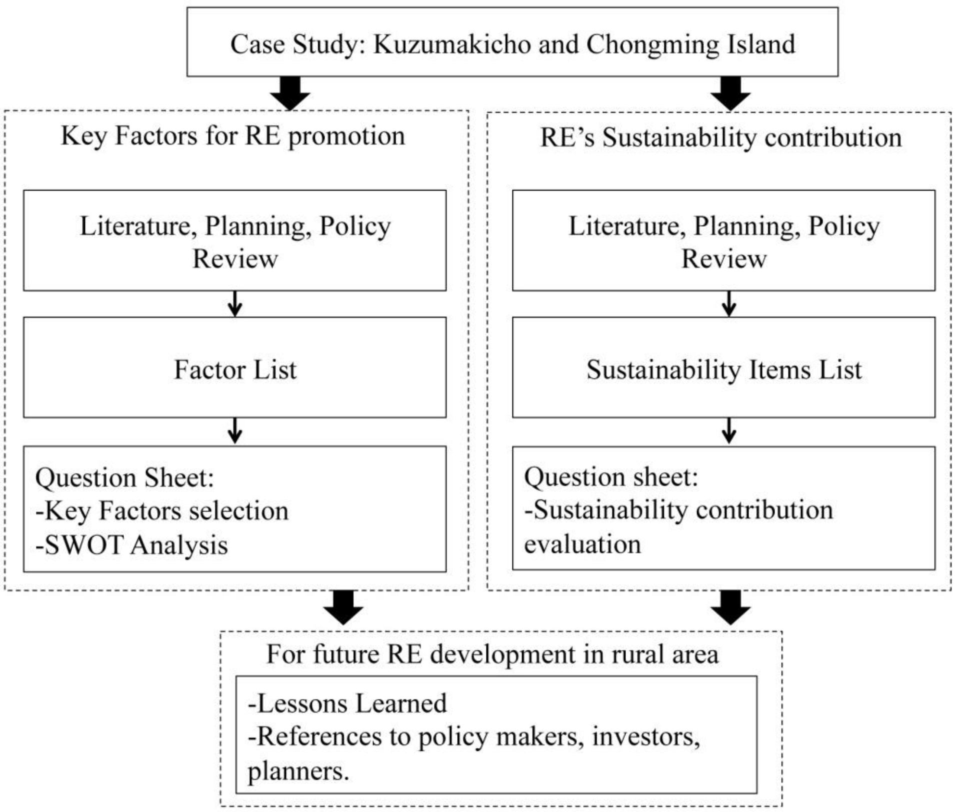

Figure 17. Methodology framework of the study. (Source: by author).

All the data reviewed is listed in Table 7 and Table 8. The review approach was to identify keywords or statement of key factor of RE promotion and RE's sustainability contribution.

Table 7. Data list for Kuzumakicho case.

Category	Year	Material
Planning and Policy	1995	Natural Environmental Conservation Regulation.
	1999	New Energy Vision.
	2002	Eco-Energy Comprehensive Project Subsidy.
	2003	Energy Saving Vision.
	2007	Biomass Town Plan.
	2012b	Global Warming Prevention Action Plan (4th).
Reports	2011	Practical Use of Local Energy Report.
	2012a	The Efforts to Clean Energy in Kuzumakicho.

Table 8. Data list of Chongming case.

Category	Year	Material
Planning and Policy	2004	Master Plan of Chongming Three Islands.
	2009	Construction Guideline of Ecological Island.
Academic Papers	2005	Wang, Zhou, et al., 2005.
	2009	Yu, Roddy, et al., 2009.
	2010	Liu, 2010.

The study involved conducting a survey through a questionnaire sheet among energy department officers in Kuzumakicho, and energy department officers in Chongming Island. The above departments were selected for their involvement in policy, planning, and management in local areas directly related to RE development. Hence, they have enough background to accurately identify the key factors involved in RE promotion, and to evaluate RE's contribution to sustainability in local areas.

Taking into account the total number of staff in the energy departments, five questionnaire sheets were hand delivered by the authors to Chongming Island energy department on June 25, 2013, and a number of 5 sheets were sent to Kuzumakicho energy department on June 24, 2013 by mail. Each questionnaire sheet package included an explanation letter, a questionnaire sheet, and a mail-back envelope with a postage stamp. The explanation letter included a description of the study objectives and an explanation of Renewable Energy and sustainable development, to ensure uniformity on the basic understanding of study aims and questionnaire contents.

The questionnaire was composed of three parts. 1) A factor list of RE promotion and SWOT analysis checklist. The key factors of RE promotion listed in the questionnaire sheet were adopted from past research, local planning and policy document review. The factors were arranged and coded in consecutive numbers, and subsequently divided into five broad classifications: environmental, administrative, social, economic, and any other(s) factors. See Table 9, Table 10.

Table 9. Factors of RE promotion in literature, local and policy documents.

Factors List	Literature/ Local plan and policy documents
Environmental	
1. Abundance of RE resources	Wang et al., 2005; Chongming Gov., 2009; Kuzumakicho Gov., 2007, 2012a; Yu et al., 2009; Liu, 2010.
2. Location	Chongming Gov., 2004, 2009; Wang et al., 2005; Liu, 2010.
3. Topography	Kuzumakicho Gov., 1995.
4. Climate	Chongming Gov., 2009; Kuzumakicho Gov., 2011, 2012b.
Administrative	
5. Municipal's planning concept	Kuzumakicho Gov., 1995,1999, 2012a; Chongming Gov., 2004, 2009; NEDO, 2008; Yu, Roddy, et al., 200;
6. Positive initiative of mayor	Chongming Gov., 2009.
7. Key person(s)	NEDO, 2008.
8. Cooperation between departments and divisions	Kuzumakicho Gov., 2007, 2012b; NEDO, 2008; Chongming Gov., 2009.
9. Position in municipal planning	NEDO, 2008.
10.High feasibility energy strategy	Chongming Gov., 2009; Kuzumakicho Gov., 2012b.
11.New energy vision/plan	Kuzumakicho Gov., 1999, 2012a.
12.Effective implementation and promotion of planning	Chongming Gov., 2004,2009; Kuzumakicho Gov., 2012b.
Social	
13.Understanding and support from outside companies	Kuzumakicho Gov., 2003, 2011, 2012a, 2012b; NEDO, 2008; Chongming Gov., 2009; Yu et al., 2009.
14.Understanding and support from local citizens	Kuzumakicho Gov., 2003, 2011, 2012a; NEDO, 2008; Chongming Gov., 2009.
15. University/experts support	Wang et al., 2005; Chongming Gov., 2009; Yu et al., 2009.
16. RE provider support	NEDO, 2008.
17. Ensuring human resources	Chongming Gov., 2009.
18. Knowledge of local RE potential	Chongming Gov., 2004; Yu et al., 2009; Kuzumakicho Gov., 2011, 2012a.
19. Knowledge of local RE potential sites	Yu et al., 2009; Kuzumakicho Gov., 2011.
20.Knowledge of scale/capacity of RE project(s)	Chongming Gov., 2004; Yu et al., 2009.
Economic	
21. Sufficient budget	Kuzumakicho Gov., 2003; Chongming Gov., 2009.
22. National or prefectural governments subsidy	Kuzumakicho Gov., 2002, 2003, 2012b; NEDO, 2008.
23. Electricity sale through FIT	Kuzumakicho Gov., 2011.
24. Ensuring economic cost-benefits	NEDO, 2008; Kuzumakicho Gov., 2011.
25.Management/maintenance cost control	NEDO, 2008; Kuzumakicho Gov., 2011.
26. Cooperation with local businesses	Kuzumakicho Gov., 2007.

Table 10. Sustainable items in literature, local plan and policy documents.

Sustainable Items	Literature/ Local planning and policy document
Environmental	
1. Global warming mitigation	Kuzumakicho Gov., 2003, 2011, 2012b; Yale University, 2005; Chongming Gov., 2009; Liu, 2010.
2. Safe to the natural environment	Yale University, 2005; Kuzumakicho Gov., 2012a, 2012b.
3. Air quality	Kuzumakicho Gov., 2003; Yale University, 2005; Chongming Gov., 2009.
4. Water quality	Kuzumakicho Gov., 2003, 2007, 2012a; Chongming Gov., 2004, 2009; Wang et al., 2005; Yale University, 2005.
5. Biodiversity	Kuzumakicho Gov., 1995; Chongming Gov., 2004; Yale University, 2005; Chongming Gov., 2009.
6. Landscape conservation	Kuzumakicho Gov., 1995, 2012a; Chongming Gov., 2009; Liu, 2010.
7. Noise	Chongming Gov., 2009.
8. Waste re-use	Chongming Gov., 2004, 2009; Wang et al., 2005; Kuzumakicho Gov., 2007, 2011, 2012b; Yu et al., 2009.
Social	
9. Connection with agriculture and forestry	Kuzumakicho Gov., 2003, 2007, 2011, 2012a, 2012b; Chongming Gov., 2004, 2009; Wang et al., 2005; Yu et al., 2009.
10. Local tertiary sector	Kuzumakicho Gov., 2003, 2007; Chongming Gov., 2004, 2009.
11. Forest management	Kuzumakicho Gov., 2007, 2012a.
12. Facility maintenance	Kuzumakicho Gov., 2007; Kuzumakicho on-site interview, June 29, 2012.
13. Local infrastructure/public facility maintenance/upgrade	Chongming Gov., 2004, 2009; Kuzumakicho Gov., 2012a, 2012b.
14. Land use	Chongming Gov., 2004; Wang et al., 2005.
15. Transportation	Kuzumakicho Gov., 2003, 2012b; Chongming Gov., 2004, 2009; Liu, 2010.
16. Energy local production local consumption	Kuzumakicho Gov., 1999, 2003, 2007, 2011; Chongming Gov., 2004; Wang et al., 2005.
17. Energy autonomy	Kuzumakicho Gov., 2012a.
18. Disaster prevention/mitigation	Chongming Gov., 2004; Wang et al., 2005; Kuzumakicho Gov., 2011, 2012a, 2012b.
19. Job creation	Rio and Burguillo, 2008; Kuzumakicho Gov., 2012a.
20. Citizen health improvement	Kuzumakicho Gov., 1995, 2011, 2012a.
21. Citizen participation	Kuzumakicho Gov., 2003, 2011, 2012a; Chongming Gov., 2009.
22. Environmental education	Kuzumakicho Gov., 2003, 2011, 2012a, 2012b; Chongming Gov., 2004, 2009.
Economic	

23. Facility investment	Kuzumakicho Gov., 2011.
24. Maintenance cost	Kuzumakicho Gov., 2011.
25. Local businesses	Chongming Gov., 2004, 2009; Kuzumakicho Gov., 2011, 2012a.
26. Revitalization of local companies	Chongming Gov., 2004.
27. Local tourism	Chongming Gov., 2004; Wang et al., 2005; Yu et al., 2009; Liu, 2010; Kuzumakicho Gov., 2012a.
28. Sale of electricity	Kuzumakicho Gov., 2012a.
29. Increase in local citizens' income	Kuzumakicho Gov., 2011, 2012a.

2) Evaluation of RE's contribution to sustainability of local areas, where five score contribution levels including, "+2 very good, +1 good, 0 neither, -1 bad, and -2 very bad" were used. Because there are three types (wind, PV/solar thermal, and biomass/biogas) of RE facilities in Kuzumakicho and Chongming Island, we only conducted evaluation of the above three types of RE facilities. The RE's contribution to sustainability listed in the questionnaire sheet were adopted from past research, local plan and policy documents review. The factors were arranged and coded in consecutive numbers, and subsequently divided into five broad classifications of environmental, administrative, social, economic, and any other(s) factors.

3) Two detailed questions: I) ranking of the top three factors from selected key factors in part 1, and writing down the reasons. II) Ranking the top three RE's sustainability contribution, and writing down the reasons.

All the responses had been received by July 5, 2013, after which we checked their validity, and subsequently analyzed them.

2.4.3 Key Factors for Local Renewable Energy Promotion: Kuzumakicho and Chongming Island.

From the 10 distributed questionnaire sheets, a total of four valid responses were received, two of them from the Kuzumakicho energy department, and two from the Chongming Island energy department.

For Kuzumakicho, both respondents identified the following key factors for local RE promotion: abundant RE resources, the municipality's planning concept, positive initiative of the mayor, new energy plan/vision, understanding and support from outside companies, RE provider support, subsidy from national or prefectural governments, and cooperation with local businesses. Also, one respondent indicated other key factors such as: position in municipal planning, effective implementation and promotion of planning, and ‘know local RE potential’ among others. SWOT analysis results were as follows. In environmental categorization, ‘Strength’ 12.5%, ‘Weakness’ 0%, ‘Opportunity’ 25%, ‘Threat’ 62.5%. In administrative categorization, ‘Strength’ 81.25%, ‘Weakness’ 0%, ‘Opportunity’ 18.75%, ‘Threat’ 0%. In social categorization, ‘Strength’ 12.5%, ‘Weakness’ 6.25%, ‘Opportunity’ 81.25%, ‘Threat’ 0%. In economic categorization, ‘Strength’ 33.3%, ‘Weakness’ 50%, ‘Opportunity’ 16.7%, ‘Threat’ 0%. Regarding an average analysis of all the categories, the proportions were as follows: ‘Strength’ 37.7%, ‘Weakness’ 13.2%, ‘Opportunity’ 39.6%, ‘Threat’ 9.5%. All the key factors identified by respondents were identified with ‘strength’ and ‘opportunity’. See Table11.

Among all the key factors, ‘Municipal’s planning concept’ was ranked as the most important factors for their local RE promotion by both respondents. For second and third most important factors, one respondent indicated ‘Abundant RE resources’, and ‘start RE promotion earlier than other municipalities’ respectively. The other respondent indicated ‘New energy plan/vision’ and ‘Abundant RE resources’ respectively as the second and third most important RE promotion factors respectively.

For Chongming Island, both respondents identified several factors as key factors for local RE promotion. They are: abundant RE resources and understanding and support from outside companies. Also, one of the respondents indicated key factors such as: municipal’s planning concept, cooperation between departments and divisions, new energy plan/vision, and enough budget among others. SWOT analysis results were as follows. In environmental categorization, ‘Strength’ 100%, ‘Weakness’ 0%, ‘Opportunity’ 0%, ‘Threat’ 0%. In administrative categorization, ‘Strength’ 75%, ‘Weakness’ 0%, ‘Opportunity’ 25%, ‘Threat’ 0%. In social categorization, ‘Strength’ 37.5%, ‘Weakness’ 25%, ‘Opportunity’ 25%, ‘Threat’ 12.5%. In economic categorization, ‘Strength’ 41.7%, ‘Weakness’ 8.3%, ‘Opportunity’ 41.7%, ‘Threat’ 8.3%. Regarding all the categories, the proportions were as follows: ‘Strength’ 59.6%, ‘Weakness’ 9.6%, ‘Opportunity’ 25%, ‘Threat’ 5.8%. Except, ‘know scale/capacity of RE’ and ‘enough budget’ that were identified in ‘Weakness’ by one respondent, the remaining key factors were categorized in ‘strength’ and ‘opportunity’. See Table 12.

Table 11. Questionnaire sheet results of key factors for RE promotion, Kuzumakicho.

Factor List	Key factors	S	W	O	T
Environmental					
1. Abundant RE resources	■	○		○	
2. Location				○	○
3. Topography					■
4. Climate					■
Administrative					
5. Municipal's planning concepts	■	■			
6. Positive initiative of mayor	■	■			
7. Key person(s)				■	
8. Cooperation between departments and divisions		○		○	
9. Position in municipal planning	○	■			
10.High feasibility energy strategy		■			
11.New energy vision/plan	■	■			
12.Effective implementation and promotion of planning	○	■			
Social					
13.Understanding and support from outside companies	■			■	
14.Understanding and support from local citizens	○			■	
15. University/experts support				■	
16. RE provider support	■			■	
17. Ensure human resources			○	○	
18. Know local RE potential	○	○		○	
19. Know local RE potential sites	○	○		○	
20. Know scale/capacity of RE project				■	
Economic					
21. Enough budget			■		
22. Subsidy from national or prefectural governments	■	○		○	
23. Electricity sale through FIT		○		○	
24. Ensure economic cost-benefits			■		
25. Management/maintenance cost control			■		
26. Cooperate with local businesses	■	■			
Others from response					
27. Start RE promotion earlier than other municipalities	○			○	

○ One response. ■Two responses.

Table 12. Questionnaire sheet results for key factors for RE promotion, Chongming Island.

Factor List	Key factors	S	W	O	T
Environmental					
1. Abundant RE resources	■	■			
2. Location		■			
3. Topography		■			
4. Climate		■			
Administrative					
5. Municipal's positive concept	○	○		○	
6. Positive initiative of mayor	○	■			
7. Key person(s)		■			
8. Cooperation between departments and divisions	○	■			
9. Position in municipal planning		○		○	
10.High feasibility energy strategy	○	■			
11.New energy vision/plan	○	○		○	
12.Effective implementation and promotion of planning		○		○	
Social					
13.Understanding and support from outside companies	■	○		○	
14.Understanding and support from local citizens	○	■			
15. University/experts support			○	○	
16. RE provider support		○		○	
17. Ensure human resources		○	○		
18. Know local RE potential	○	○		○	
19. Know local RE potential sites			○		○
20.Know scale/capacity of RE project	○		○		○
Economic					
21. Enough budget	○	○	○		
22. Subsidy from nation or prefecture	○	○		○	
23. Electricity sale through FIT				○	○
24. Ensure economic cost-benefits	○	○		○	
25. Management/maintenance cost control		○		○	
26. Cooperate with local businesses		○		○	
Others from response					
None					

○ One response. ■Two responses.

One respondent ranked the most important top three key factors as follows: ‘abundant RE resources’, ‘municipal’s planning concept’, ‘subsidy from national or prefectural governments’. Another ranked them as follows: ‘high feasibility energy strategy’, ‘enough budget’, and ‘abundant RE resources’. Although the ranking was different, the most important three key factors they pointed out were the same: abundant RE resources, positive RE concept and strategy, and financial support.

2.4.4 Renewable Energy’s Sustainability Value: Kuzumakicho and Chongming Island.

For Kuzumakicho, regarding RE’s sustainability contribution, perception of these contributions are different among respondents. One respondent indicated wind energy has a ‘+1 good’ contribution to sustainability’, and safe to the natural environmental’. In contrast, another respondent indicated it as having ‘-1 bad’ contribution. As shown in Table 11, wind energy’s positive contributions evaluated as ‘+2 very good’ by both respondents included: ‘environmental education’ and ‘local tourism’. PV/solar included: ‘safe to the natural environment’, ’local infrastructure/public maintenance/upgrade’, and ’environmental education’. Biomass/biogas included: ‘waste re-use’, ‘connection with agriculture and forestry’, ’energy local production, local consumption’, ‘energy autonomy’, and ‘environmental education’. Items had negative evaluation, such as: noise, land use, energy local production-local consumption, and citizen participation were identified for wind energy facilities. Landscape conservation, job creation, and facility investment were identified for PV/solar facilities; while air quality, facility maintenance, and maintenance cost were identified for biomass/biogas facilities. See Table 13.

Among all the sustainability items, ‘connection with agriculture and forestry’ was ranked as the most important by both respondents. For second and third important items one respondent indicated ‘energy local production local consumption’ and ‘environmental education’ respectively, while the other respondent indicated ‘energy autonomy’ and ‘local tourism’.

Table 13. Questionnaire sheet results for RE's sustainability contribution, Kuzumakicho.

Sustainable Items	Wind Energy	PV/solar	Biomass Biogas
Environmental			
1. Global warming mitigation	+2, +1	+1, +1	+1, 0
2. Safe to the natural environment	+1, -1	+2, +2	+2, -1
3. Air quality	0, 0	0, 0	0, -1
4. Water quality	0, 0	0, 0	0, +1
5. Biodiversity	0, -2	+2, 0	+2, -1
6. Landscape conservation	+1, +1	0, -1	0, 0
7. Noise	-1, -2	0, 0	0, 0
8. Waste re-use	0, 0	0, 0	+2, +2
Social			
9. Connection with agriculture and forestry	+1, 0	0, 0	+2, +2
10. Local tertiary sector	0, +2	0, 0	+1, +1
11. Forest management	0, 0	0, 0	+1, +2
12. Facility maintenance	0, +1	0, +1	-1, -1
13.Local infrastructure/public maintenance/upgrade	0, 0	+2, +2	-1, +1
14. Land use	0, -1	0, 0	0, -1
15. Transportation	0, 0	0, 0	0, +1
16. Energy local production local consump	-2, 0	+2, +1	+2, +2
17. Energy autonomy	-2, 0	+2, +1	+2, +2
18. Disaster prevention/mitigation	-2, 0	+2, +1	+1, +1
19. Job creation	0, +1	-2, 0	0, +2
20. Citizen health improvement	0, 0	0, 0	+1, +2
21. Citizen participation	-1, 0	+1, +1	+1, +1
22. Environmental education	+2, +2	+2, +2	+2, +2
Economic			
23. Facility investment	0, -1	0, -1	0, +1
24. Maintenance cost	0, +1	0, +1	-2, -1
25. Local business	0, 0	0, 0	0, +1
26. Revitalize local company	+1, 0	+1, +1	+1, +1
27. Local tourism	+2, +2	+2, +1	+2, +1
28. Electricity sale	0, +2	0, +1	0, 0
29. Increase local citizen's income	+1, 0	+1, +1	0, +1
Others from response			
None			

For Chongming Island, respondents indicated several items as positive for '+2 very good' and '+1 good' scores. They include: global warming mitigation, energy local production-local consumption, and local tourism among others. The only PV/Solar's sustainability items evaluated as '+2 very good' by both respondents was biodiversity. Like wind energy, several items were evaluated as positive for '+2 very good' and '+1 good' scores. They include: safe to the natural environment, facility maintenance, energy autonomy, and citizen participation among others. For biomass/biogas, their sustainability items evaluated as '+2 very good' by both respondents were: waste re-use, connection with agriculture and forestry. Items which had negative evaluation, such as such as: noise, biodiversity, landscape conservation were identified for wind energy facilities; waste re-use, landscape conservation, environmental education were identified by one respondent. For PV/solar facilities; air quality, facility maintenance, land use, and disaster prevention/mitigation were identified for biomass/biogas facility. See Table 14.

One respondent ranked the most important sustainability items as follows: 'air quality', 'safe to the natural environment', 'waste re-use'. Another one ranked them as follows: 'global warming mitigation', 'energy autonomy', and 'revitalization of local companies'.

After calculating the total mean score, each RE's total sustainable contribution score was calculated by environmental, social, economic categorization in Kuzumakicho and Chongming Island, see Table 15. According to the SWOT analysis results, in Kuzumakicho case, most of the environmental factors (62.5%) were identified as 'threats'. This could be due to its remote location with no railway or Shinkansen (bullet train) through the town and far away from prefectural capital city Morioka (90 min by bus), as well as extreme cold in winter (minimum -16℃). As revealed in key factors selection, because of positive attitude by the municipal government, early start of local RE development, and formulation of local planning policies, 81.25% of administrative factors, were identified as 'strengths'. During local RE development process, there is a lot of technical support from outside. There is biomass plant technology support from NEDO, biogas technology support from T. Machinery Company in Tokyo, and financial support from Ministry of the Environment, Iwate prefecture and NEDO among others. Thus social factors were prominently identified as 'opportunities'. Due to the local budget limitations and high RE facility maintenance cost, 50% of economic factors were identified as 'weaknesses'.

Table 14. Questionnaire sheet results for RE's sustainability contribution, Chongming Island.

Sustainable Items	Wind Energy	PV/solar	Biomass Biogas
Environmental			
1. Global warming mitigation	+2, +1	+2, +1	+1, +1
2. Safe to the natural environment	+2, +1	+2, +1	+1, +1
3. Air quality	+1, 0	+2, +1	0, -1
4. Water quality	+2, 0	+1, 0	+1, +1
5. Biodiversity	0, -1	+2, +2	+1, +1
6. Landscape conservation	0, -1	-1, +1	0, +1
7. Noise	-1, -1	0, 0	0, 0
8. Waste re-use	0, 0	-1, 0	+2, +2
Social			
9. Connection with agriculture and forestry	0, 0	0, 0	+2, +2
10. Local tertiary sector	0, 0	0, +1	+1, 0
11. Forest management	0, 0	0, 0	+2, 0
12. Facility maintenance	+1, +1	+2, +1	-1, +1
13. Local infrastructure/public facility maintenance/upgrade	+1, 0	0, +1	+1, 0
14. Land use	0, -1	+2, 0	+1, -1
15. Transportation	-1, 0	0, 0	0, -2
16. Energy local production, local consumption	+1, +2	+1, +2	0, +2
17. Energy autonomy	+1, +2	+1, +2	+1, +2
18. Disaster prevention/mitigation	0, +1	0, +1	0, -1
19. Job creation	0, +1	0, +1	+1, +1
20. Citizen health improvement	+1, 0	+1, 0	+1, 0
21. Citizen participation	0, 0	+1, +2	+1, +2
22. Environmental education	0, +1	-1, +1	0, +1
Economic			
23. Facility investment	0, +2	0, +2	+1, +2
24. Maintenance cost	0, +1	0, +1	+1, +1
25. Local business	0, +2	0, +1	0, +1
26. Revitalize local company	0, +2	+1, +1	0, +1
27. Local tourism	+2, +1	0, +1	+1, 0
28. Electricity sale	+2, 0	+2, 0	+2, 0
29. Increase local citizen's income	0, +1	0, +1	+1, +1
Others from response			
None			

Table 15. Different RE resources' total mean score results in Kuzumakicho and Chongming Island.

Case	Kuzumakicho			Chongming Island		
RES	Wind	PV/Solar	Biomass Biogas	Wind	PV/Solar	Biomass Biogas
Environmental	0	3.5	3.5	2.5	7.0	6.0
Social	0.5	9.0	14.0	5.5	9.5	8.5
Economic	4.0	4.0	2.5	6.5	5.0	6.0
Total	4.5	16.5	20.0	14.5	21.5	20.5

In the Chongming Island case, with regard to environmental factors, 'strength' was particularly prominent (100%). Indeed, unlike the remote location and cold winter in Kuzumakicho, its location (25km from Shanghai), climate (annual temperature range 4℃-30℃) in Chongming Island are good. 75% of administrative factors were identified as 'strengths', while social factors got a close proportion among 'strength' 37.5%, 'weakness' 25%, and 'opportunity' 25%. This could be due to local government's effort on RE development goal in upper level master plan, such as: Master Plan of Chongming Islands (2005-2020), but there is still lack of support from university/experts and RE provider. If these factors improve, they can be 'opportunities' in the future. 'Strength' (41.7%) and 'opportunity' (41.7%) coexist for economic factors in Chongming Island, considering the quick pace of economic and RE development in China; this is not hard to understand.

Secondly, according to the sustainability items evaluation results, different RE resources revealed different sustainability characteristics. In Kuzumakicho case, the main sustainability contributions of wind energy were: environmental education and enhanced local tourism. After the Eco wind farm was built in 1998, the total tourist number doubled from 180,000 (1999) to 370,000 (2000), and has achieved about 550,000 (2009) over 10 years (Nelsis Editorial Office, 2011). Green energy courses provided by the local energy department for free, an elementary school short-stay course, local accommodation and restaurants provided for tourists, also contributed to the increase and chances for environmental education. As for PV/solar facilities, their 'safe to the environment', 'local infrastructure/public facilities maintenance/upgrade', and 'environmental education' contributions were highlighted by the respondents. After the Great North Eastern Japan earthquake on March 11th, 2011, Kuzumakicho experienced three times power cut because of energy shortage (On-site Interview June 29, 2012, with person in charge of environmental energy in Kuzumakicho energy department), the local government started to install PV on local community centers' rooftops, to ensure minimal power supply in the center for local citizen during power cut periods. Therefore, this might be the reason they indicated 'local infrastructure/public facility maintenance/upgrade' with high scores. Biomass/biogas was highlighted for the largest number of contributions, 'waste re-use', 'connection with agriculture, forestry', 'energy local production, local consumption', 'energy autonomy', and 'environmental education'. The close connection between biomass/biogas with local agriculture, forestry and waste re-use is obvious through material supply of wood pellets, wood chips, and livestock waste. This can be also considered as an advantage, as well as a characteristic of biomass/biogas development in rural areas. By comparing total score of the above three RE resources (Table 13), the low contribution score of wind energy to local sustainability maybe 'wind energy electricity is not used by local people'. Although wind energy shares the largest in facility capacity, instead of being used by local people, big electricity companies send this electricity through the National grid to other areas. As mentioned above, the tight connection between biomass/biogas material supply and local agriculture, forestry made biomass/biogas had the highest scores. However, to balance the cost-benefits is a task for biomass/biogas in rural areas, such as: initial investment, maintenance cost issues (On-site Interview June 29, 2012, with person in charge of environmental energy in Kuzumakicho energy department). Like biomass/biogas, the economic issues limit further development of PV/solar in Kuzumakicho.

In Chongming Island case, one of the responses identified the sustainable contribution of wind energy as contributing to: 'global warming mitigation', and 'local tourism' among others. Like wind energy in Kuzumakicho, the wind energy electricity is sent to the national grid and not used by local people, thus wind energy facilities seem only to be used for tourism purposes in the local area. For PV/solar, their contribution to 'biodiversity', 'safe to the environment', 'energy autonomy', and 'citizen participation' contribution were highlighted. The Mage-Solar farm (1MW) built in 2010 is sending electricity to local area, thus helping on the 'energy autonomy' aspect. Like biomass/biogas in Kuzumakicho, the two main advantages of biomass/biogas in rural areas as mentioned above: waste re-use and connection with local agriculture and forestry were highlighted again. By comparing total score of these three RE resources in Table 15, the difference between the total score is comparatively smaller than that in Kuzumakicho. The score highlighted the economic contribution of wind energy, and the social contribution of PV/solar and biomass/biogas as well.

2.5 Discussion

As literature and case review shown, RE can provide specific environmental, social, and economic benefits. Nonetheless, the negative impacts brought about by RE facilities should not be ignored. Among these, the visual impact of wind turbines is considered as one of the leading causes of public opposition. This puts a new challenge for landscape architecture research and opens up possibilities with new practical application in the field.

As the scale and number of wind turbines increases, comprehensive evaluation at city or settlement level has been lacking, especially in Asian countries. It is found that in the energy planning process, visual impact evaluation should be integrated in the analysis procedure. This provides aesthetic considerations, consequently decreasing public opposition to wind energy and other RE facilities.

With regard to the planning of RE, previous studies have been mostly focused on estimation of energy potential and mapping, and the full introduction of GIS-based planning approach at the regional level has been lacking. Theoretically, previous studies provided significant references for this study in the following areas. They are: general steps of the planning approach, estimation of energy potential method, and site selection criteria. Based on previous works, it is possible to develop a new GIS-based approach for RE planning at regional level. Also, this study emphasizes that some basic concepts of spatial planning, such as spatial organization, public participation, and regional source balancing are worth to be integrating in the RE planning process. Thus, it is possible to propose and develop a wholistic concept of “Spatial Planning for RE”.

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CHAPTER 3

RENEWABLE ENERGY FACILITIES ON THE LANDSCAPE: VISUAL IMPACT OF WIND FARMS IN CHOSHI CITY, JAPAN.

"Visual Impact Evaluation of Wind Farms: a Case Study of Choshi City, Japan."
Published at: *Civil and Environmental Research. 3(7), 97-106*.

3.1 Introduction

Since The Great North Eastern Japan earthquake on March 11, 2011 and the consequent nuclear disaster, the Japanese government has been making efforts to expand the installation and use of green, safe Renewable Energy (RE). Among all the RE resources, wind energy has the highest potential at 1,900MkW out of the total RE potential of 2,081MkW (Japanese Ministry of Environment, 2011a). Wind energy may become a popular energy source for local use in the coming few decades. It may also play a vital role in the post earthquake reconstruction, in Japan. However, an increase in size and number of wind turbines increase the visual impact to the landscape too. Various studies show that visual impact is one of the main negative impacts of wind farms, and the leading cause of public opposition (Thayer and Freeman, 1987; Wolsink, 2000, 2007; Kaldellis, 2005). In Japan, most of the studies have focused on perception research (Sakamoto et al., 2004; Ohgishi et al., 2006). A "Technical Guideline for wind energy facilities in high scenic areas" was developed by Japanese Ministry of Environment (2011b). This was based on their work on visual impact of wind turbines in high scenic areas such as National Parks since year 2005. Highly scenic areas have received more attention than normal local areas in Japan. Normal local areas require attention, too, as they are perceived daily by the residents due to proximity to their living quarters.

Although visual impact is difficult to evaluate objectively, some applications and regional assessments have been accomplished (Lothian, 2007; Moller, 2006). Several assessment methods have been developed for different levels, such as GIS-based assessment, Multi-criteria Analysis, and the Spanish Method. However, there is lack of integration of visual impact into the evaluation methods at both city and community levels. GIS-based assessment is suitable for regional and city level evaluations. It can be overlaid with visual condition analysis, land use, and population analysis among others. Multi-criteria analysis is now widely used to analyze multiple elements of the target site such as physical attributes (landscape form, topography and land use) and aesthetic attributes, such as color and texture among others (Leung and Yang, 2012). However, evaluation is not specialized at the settlement level, and factors can change based on the target site, making it difficult to ascertain the reliability of factor selection and evaluation. The Spanish Method (Hurtado et al., 2004) was developed for local level evaluation, aiming to assess a wind farm's visual impact on a target settlement. A 'Visual Impact Evaluation Matrix' for scoring including five coefficients, was proposed. The only empirical application carried out has been on Crete Island in Greece (Tsoutsos et al. 2009).

Each of the above methods has different characteristics. In this study, a combination of those methods is developed, so as to benefit from their advantages. This new proposed methodology hybridizes two levels of visual impact evaluation. It combines GIS-based Viewshed analysis for city level evaluation and the Spanish Method for community level evaluation. The reasons we chose the Spanish method over the Multi-criteria analysis for the study were: 1) it is a specialized method for community level evaluation. 2) it has certainty of factors compared to Multi-criteria analysis and 3) to provide empirical evidence and evaluation of its application outside European countries. Taking into account that it is the first time Spanish method is used in an Asian country, it is necessary to verify the effectiveness of its results in the region. Because the Spanish method does not differtiate between for different landscape background factors such as wind turbines layout, in the community level evaluation I combined it with a questionnaire survey to make up for this deficiency. Finally, the proposed methodology was applied to Choshi city in Japan as a case study.

This study focused on local areas and had the following aims: 1) to develop a methodology applicable at both city and community level and test it through a case study, 2) to examine practicability and accuracy of the Spanish method at the community level in an Asian country (Japan), 3) to do preliminary studies on the new factors that were not considered by the Spanish method such as different landscape backgrounds and wind turbine layouts, using a questionnaire survey.

In Japan, there are basically two types of Environmental Impact assessment (EIA) policy systems related to wind farms. One is the official system. Although Japanese Environmental Impact Assessment Law (1997) does not clearly point out whether assessing wind farm projects is necessary or not (Table 16), there are still four provinces which have their own ordinances at the province level. Another is the un-official policy system, based on the wind farm EIA guideline drawn out by NEDO (the New Energy and Industrial Technology Development Organization). Wind farm project developers can get financial subsidies from NEDO if they draw up EIA report which follows NEDO's wind farm EIA guidelines.

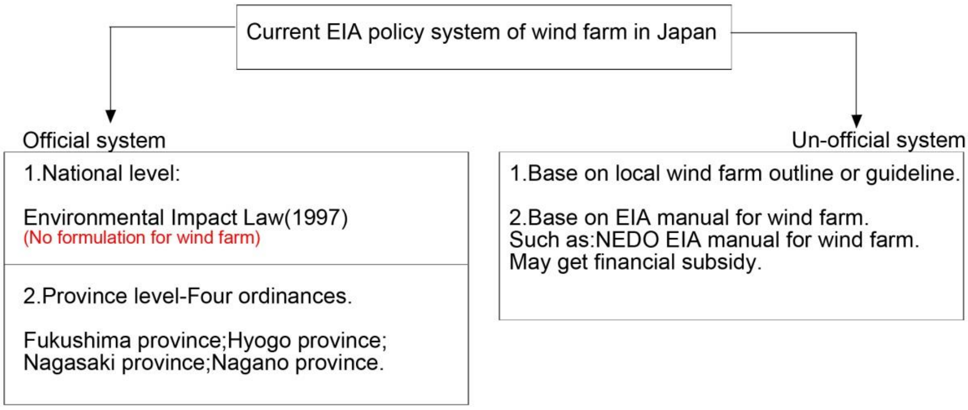

Figure 18. Environmental assessment system of wind farm in Japan. (Source: by author).

Table 16. Assessment-necessary electrical projects in Japanese Environmental Impact Assessment Law. (Japan Ministry of the Environment, 1997).

○Hydro-power plant	Capacity: 30,000kW~	Capacity: 22,500 kw-30,000 kW
○Thermal power plant	Capacity: 150,000kW~	Capacity: 112,500 kW-150,000 kW
○Geothermal power plant	Capacity: 10,000kW~	Capacity: 7500kW-10,000 kW
○Nuclear power plant	All	All

3.2 Visual Impact Evaluation in the Spatial Planning

It is discovered that environmental planning is a significant part in spatial planning. In “Guiding Principles for Sustainable Spatial Development of the European Continent”, the European Conference of Ministers Responsible for Spatial Planning (CEMAT) pointed out the disciplines that spatial planning linked with (CEMAT, 2000). They are land use planning, urban-rural planning, transport planning, environmental planning, and other planning such as economic and community planning. See Figure 19.

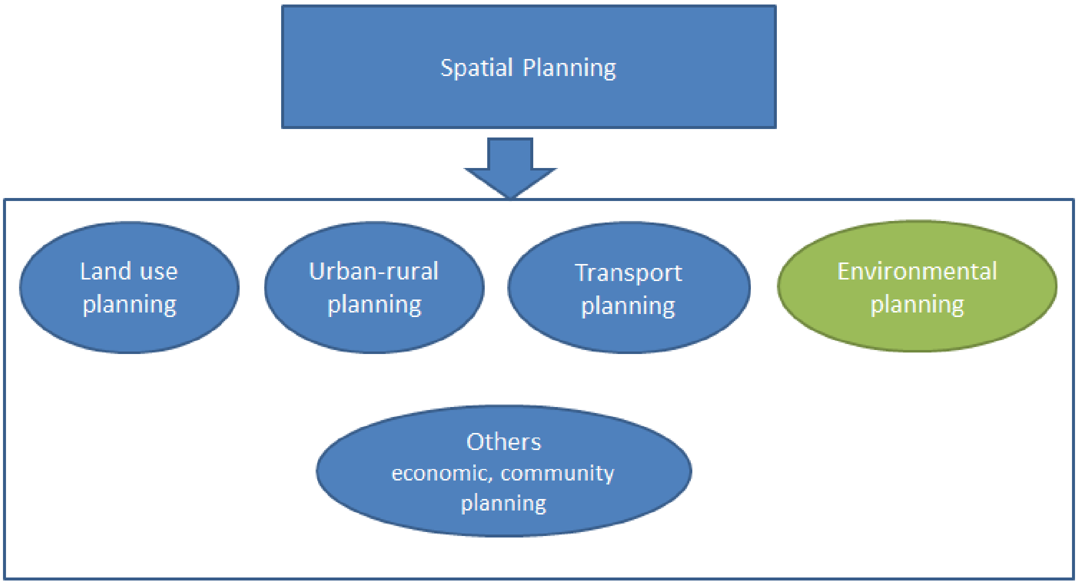

Figure 19. Disciplines that spatial planning linked with.

(Source: based on CEMAT, 2000. By author).

Besides the close relationship between spatial planning, land use and socio-economic aspects, the environmental aspect and its plan (environmental plan) is one of the most important factors within spatial planning system. As one of the earliest countries that established a spatial planning system, Switzerland created their "Spatial Planning Law" in 1979. The "Spatial Planning Law" carried great expectations towards landscape/environmental conservation (Kinoshita, 1998). The Natural Resources Conservation Plan (Environmental Plan) was a comprehensive plan that involved various factors, such as land use, biodiversity, cultural heritage conservation and so on. The Commission of European Communities (1997) pointed out that there are three main aims in spatial planning, 1) to create more rational land uses with better distribution, 2) to balance demand for development, with the need to protect the environment, and 3) to achieve social and economic objectives. In 2004, the EU started their new European Landscape Convention. In the Landscape Convention, many future tasks were proposed, such as improving individual and social well-being, raising awareness, training and education, and public participation, among all of which, the relationship between landscape and spatial planning was emphasized again.

For environmental planning in spatial planning, Environmental Impact Assessment (EIA) is its main consideration. According to CEMAT (2000), environmental planning is "a relative new discipline aiming at merging the practice of urban/regional planning with concerns of environmentalism". It works closely with Environmental Impact Assessment (EIA). They explained environmental planning as "the realization of rigorous EIA of projects and programs." There are various areas that EIA addresses, such as land use, noise, air, housing, water, ecosystems, and visual aspects.

With regard to visual aspects of RE facilities, the enormous size of wind turbines among all the RE facilities leads to high potential of impacting visual aspects of the landscape (Figure 20). However, little attention has been paid to this topic. Thus, this chapter focuses on visual aspects of wind farms/turbines in the context of spatial planning for RE (Figure 21), hoping to provide an applicable methodology for visual impact evaluation of wind farms at both city and community level. Another purpose is to evoke awareness of the visual impact of RE facilities, especially wind turbines, in the landscape architecture and urban-rural planning fields.

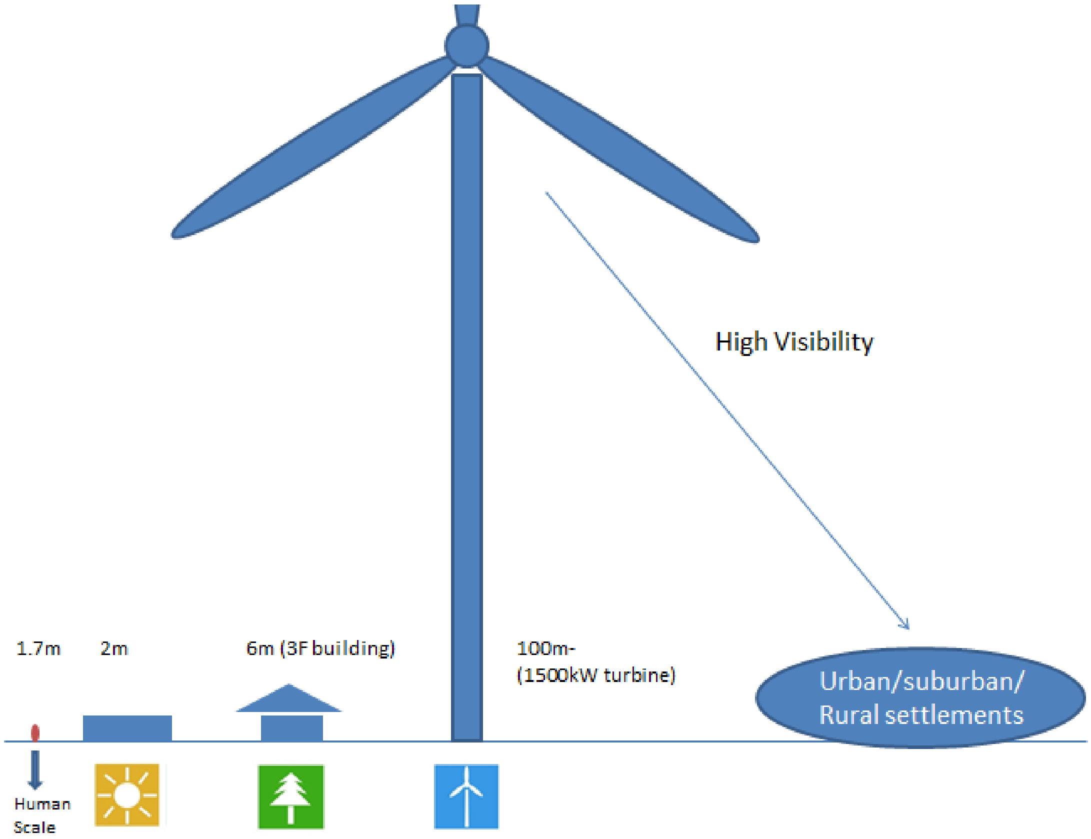

Figure 20. Size comparison of different RE facilities. (Source: by author).

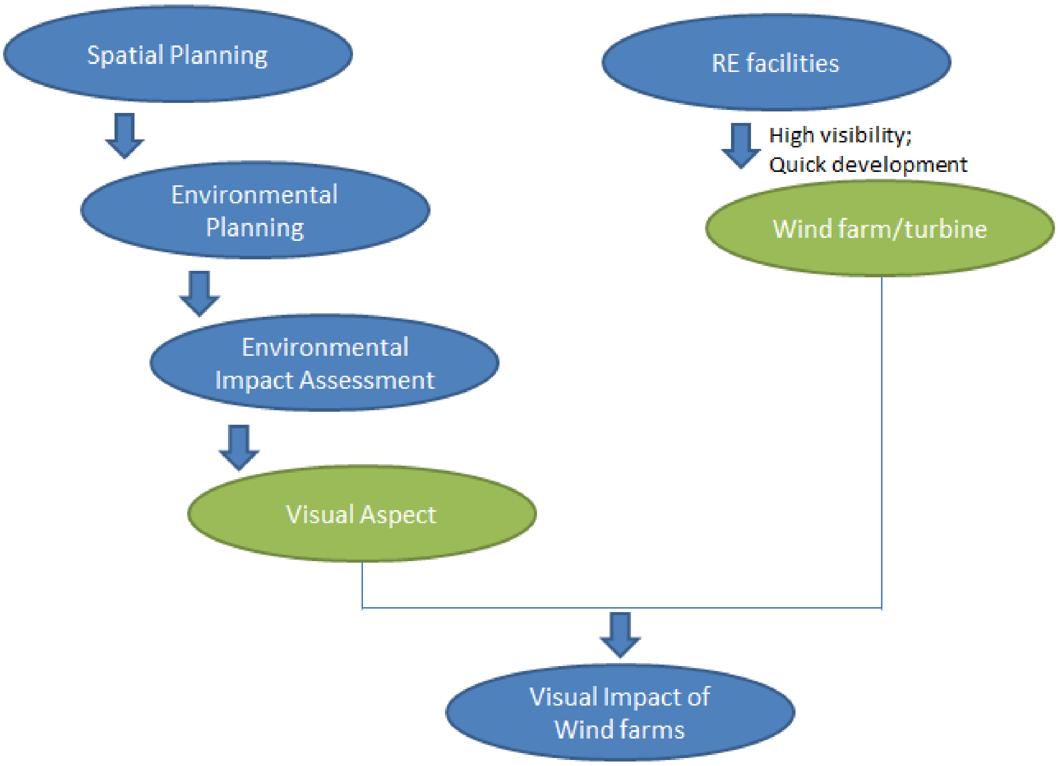

Figure 21. The position of visual impact evaluation in spatial planning and the reason to select wind farm/turbine among all the RE facilities. (Source: by author).

3.3 Brief Description of Choshi city, Japan

Choshi city is located in Chiba Prefecture, Japan, at the easternmost part of Boso Peninsula. The city covers an area of 83.91 km^2, with a population of 69,954. It has an average annual inland wind speed of 6.5m/s (NEDO, 2010) and offshore wind speed that reaches 7.5m/s. Choshi has the largest number of wind turbines in Japanese Kanto region. The city has a total wind energy production capacity of 53,560kW (Choshi City Gov., 2010a). Between years 2001-2009, wind turbines increased from 1 to 34 within 10 wind farms, see Figure 22.

The reasons we selected Choshi city are as follows.

- Enough wind turbines in city area: unlike other areas which just have one or two wind turbines on site, Choshi city currently has a of total 34 wind turbines. The quantity of wind turbines in Choshi city are enough to support the ZVI analysis base on the city scale.
- Turbine number has been increasing by year: from 2001-2009, the number of wind

turbine increased from 1 to 34.

- Independent settlements in suburban area: in Choshi suburban area, a lot of independent settlements are existing, it is a necessary condition in using the Spanish method, because the Spanish method is an evaluation methodology developed for suburban settlements or villages, not for urban areas or other locations. Specifically, to use Spanish method in evaluating visual impact, the two selected settlements were: Sarudacho (猿田町) and Tokoyodacho (常世田町).
- Wind energy development potential in the future: recently, NEDO and Tokyo Electric Power Company(TEPCO) have been doing off-shore wind farm testing in the sea near Choshi, moreover, due to rich wind energy resource in Choshi, there is possible that more wind farms will be built, which means the wind turbine number may continuously increasing in the future in Choshi.

At the community level, we selected the Sarudacho and Tokoyodacho settlements located in the west of Choshi City. They belong to the Northern settlement area and southern settlement area in suburban Choshi respectively, and have direct visibility to wind turbines (visible wind turbine more than zero with limited visual disturbances from the topography and vegetation. See Table 17 for site investigation detail of settlement selection.

Sarudacho had a population of 700 people in 279 households (Choshi City Gov., 2010b). Three wind farms, Shiishiba, Takadacho, and Choshi wind farms surround it. This community area has a hilly and mostly forested topography. An East Japan Railway (JR) train station within the community leads to a high frequency of residents passing by and seeing the wind turbines. Tokoyodacho had a population of 230 people in 66 households (Choshi City Gov., 2010b). It is located at the center of all the wind farms, and thus the people there has a high exposure to the wind turbines. This community has mixed farmland and forest landscapes with a combined hilly and flat topography.

Table 17. Site investigation detail for settlement selection.

Time	Weather Temperature	Area	Transport	Route (Checked settlements)	Objective
2010.11.6 11:00-16:00	Sunny 17℃	North settlement area	Walk	Sarudacho—Funakicho—Shomyojicho—Nakajimacho nichome—Mikadocho—Okanodayicho nichome—Akadtsukacho—Miyakemachi nichome	Understand general visual condition of wind turbine in settlements
2010.12.5 11:00-16:00	Sunny 14℃	South settlement area	Bike	Misakicho—Obamacho—Oyadacho—Tokoyodacho—Yagicho	Deeper understanding of settlements
2010.12.9 11:00-17:30	Sunny 13℃	Specific settlements	Walk	Saradacho Tokoyodacho	Specific settlement survey

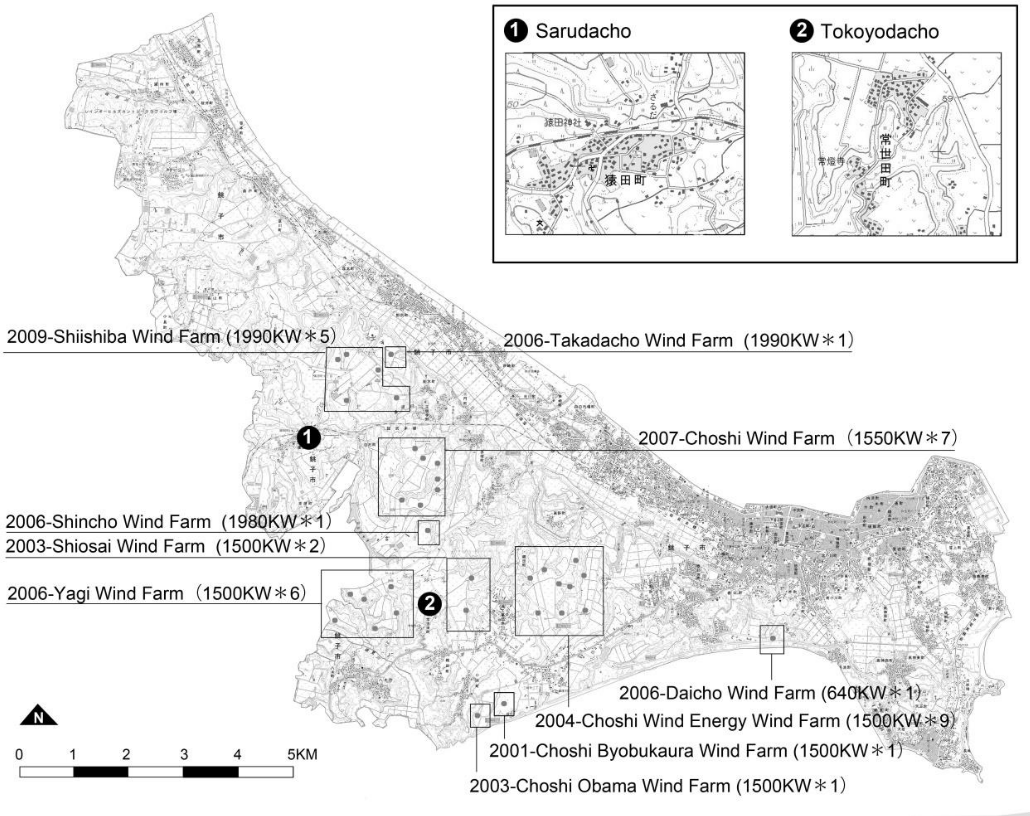

Figure 22. Wind farm and community map in Choshi city. (Source: by author).

3.4 Research Methodology

The methodology included two parts: city level evaluation and community level evaluation. City level evaluation used ArcGIS Viewshed analysis to quantify the Zone of Visual Influence (ZVI) of wind farms. It helped understand the changing and current visibility condition of wind farms. Community level evaluation used the Spanish method combined with a questionnaire survey. We used the questionnaire survey to verify the practicability and accuracy of the Spanish method. This methodology facilitates understanding of the visibility conditions of wind farm infrastructure to planners, investors, and policy makers. The framework of the methodology is as illustrated in Figure 23.

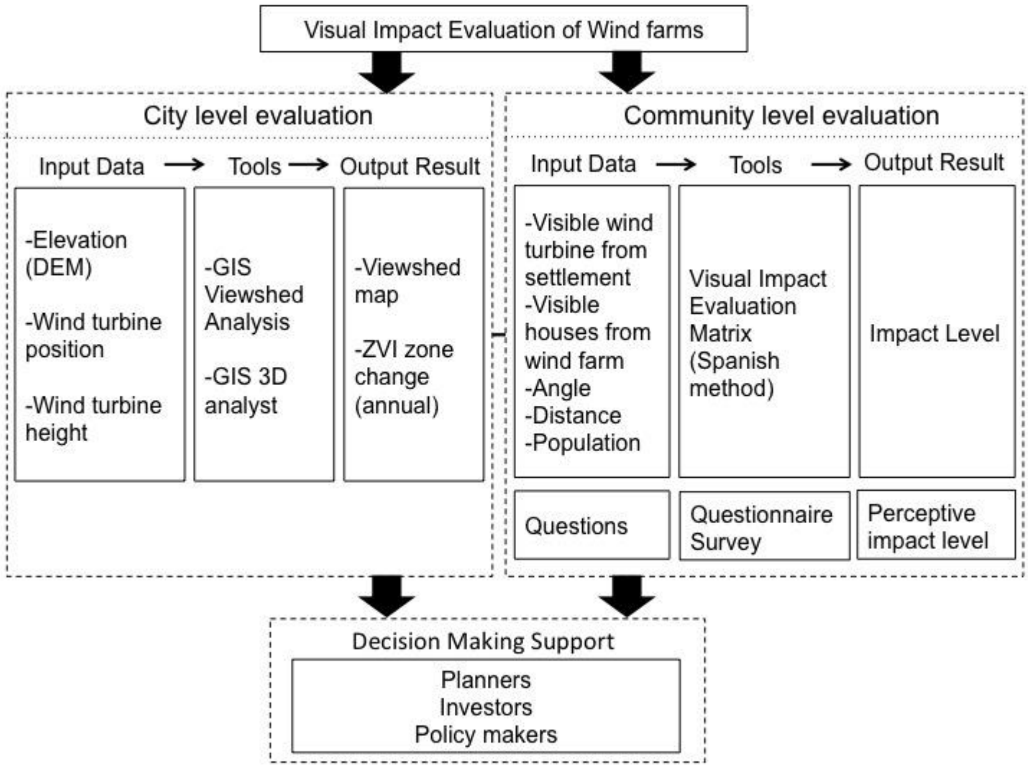

Figure 23. Methodology framework for visual evaluation at both city and community levels. (Source: by author).

3.4.1 GIS Viewshed Analysis

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, which we carried out using ArcGIS 9.2 (ESRI, 2010). Based on topographic and wind turbines data, we used this analysis to find out the ZVI area change from 2001 to 2009 in Choshi. GIS data preparation process in ArcGIS was as follows. We sourced elevation map (1/25,000; contour interval 5m; JPG) from Geospatial Information Authority of Japan (2010). We traced over contours using AutoCAD 2008. Then we inserted these contours (Figure 24) into ArcGIS and edited elevation attribute for each of them. We generated Triangular Irregular Network (TIN) from the contours (Figure 25) and converted TIN into raster data using ArcGIS-"3D Analyst"- "Convert TIN To Raster" tool. We carried out Viewshed analysis using ArcGIS as follows: added wind turbines in different point layers by year (data sample is as shown in Table 17, find more in Appendix 3). Included Wind turbines height attributes in two categories, where one was 100m (1,500kW, blade included), and the second 118m (1,990kW, blade included). Then we ran GIS Viewshed analysis (surface analysis tool) for each point layer was based on Raster data, and output of an annual Viewshed map. In the meantime, the total wind turbine visible area was calculated as ZVI.

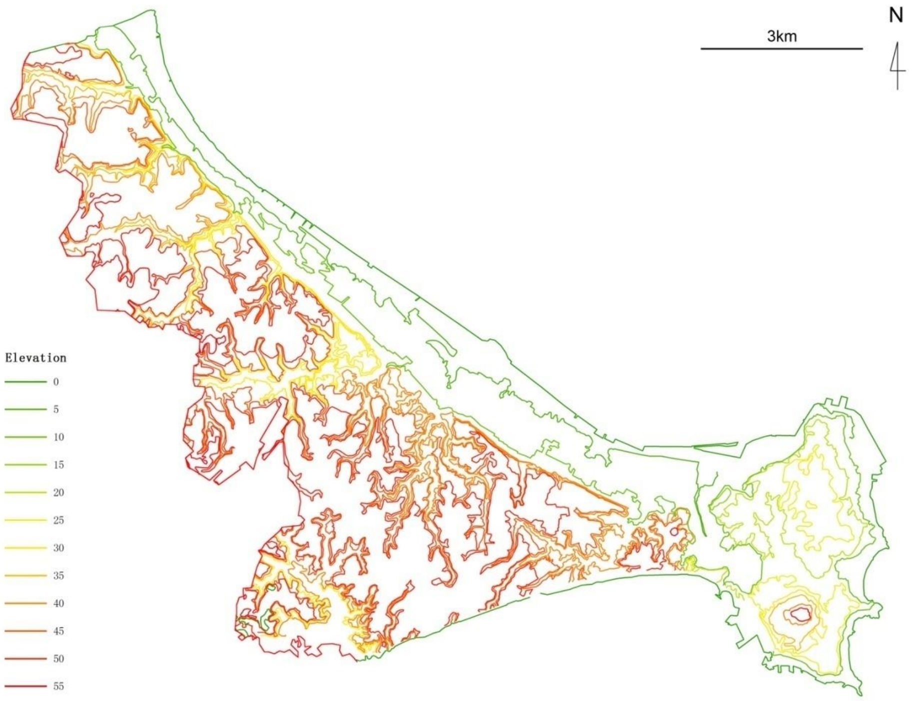

Figure 24. Topography map of Choshi city. (Source: by author).

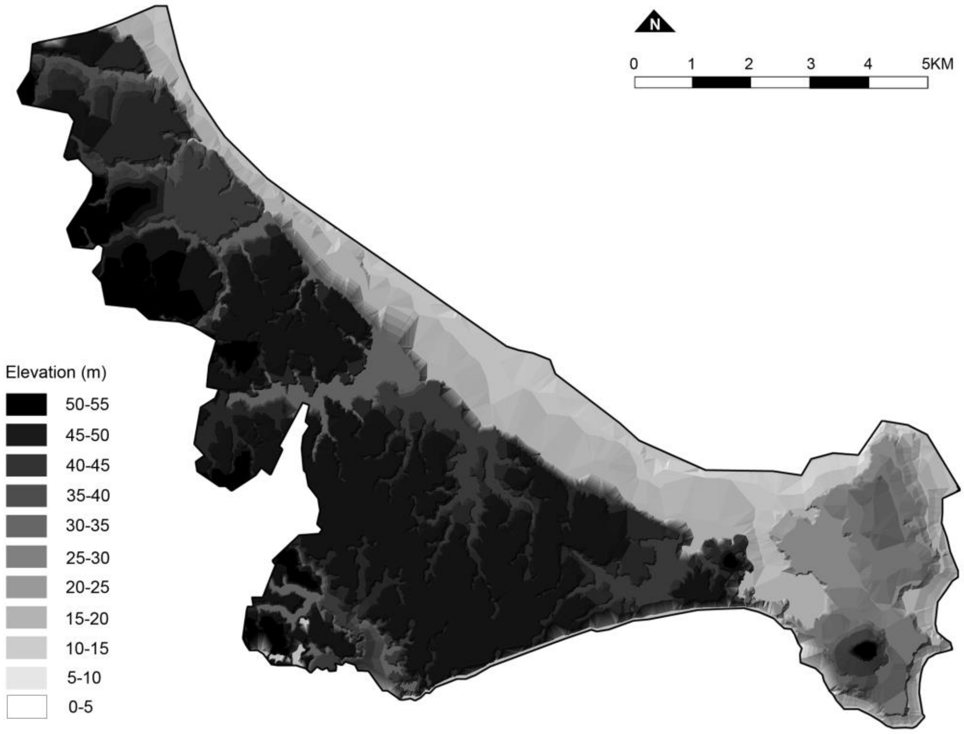

Figure 25. TIN map of Choshi city. (Source: by author).

Table 18. Wind turbine location sample (NEDO, 2010).

Year	Wind farm	Number of wind turbine	Location Detail
2001	Byobukaura	1	35°42′16.0″N, 140°46′26.0″E
2003	Obama	1	35°42′10.0″N, 140°46′6.0″E
	Shiosai	2	35°42′28.0″N, 140°46′8.0″E 35°42′14.0″N, 140°46′3.0″E

3.4.2 Spanish Method.

At the community level, we applied the Spanish method to Sarudacho and Tokoyodacho settlements in suburban Choshi. The Spanish method (Hurtado et al., 2004) proposed "Visual Impact Evaluation Matrix (VIEM)" is suitable at the community level. VIEM has five coefficients which can be defined as follows.

a) Visibility coefficient of wind farm from settlement. (Hurtado et al., 2004).

The village is split into several areas to determine this coefficient. If the visual impact varies inside the village, this coefficient will be an approximation to a medium value. The way to calculate this coefficient is by the expression,

$$a = \frac{\sum_{i=1}^{n} Xi/WM}{n}$$

where *n* is the number of areas inside the village with different views of the wind farm, *Xi* is the number of wind turbine visible from area i, and *WM* is the total number of wind turbine in the wind farm.

b) Visibility coefficient of the village from wind farm. (Hurtado et al., 2004).

This measure the number of houses visible from the wind farm (from each wind turbine), from among the total number of houses of the village. This coefficient is not dependent on the previous one.

$$b = \frac{\text{number of houses visible from the wind farm}}{\text{total number of houses in the village}}$$

c) Visibility coefficient of the wind farm taken as a cuboid. (Hurtado et al., 2004).

The wind farm can be visualized inside a cuboid of regular shape. This enables one to say that wind farm could be seen from the front, diagonally or longitudinally, depending on the side of viewing. Thus, a factor "*v"* can be assigned for evaluation inside the matrix VIEM (Figure 26). Also, there is direct relation with the number of wind turbines belonging to the wind farms, because 3 wind turbines are not the same as including 25 wind turbines. For that, a quantity factor "n" is added. With these two values, the visibility coefficient can be calculated:

$$C = n \times v$$

Table 19. Correction factor of wind turbine aspect.

View	v factor
Fontal	1.0
Diagonal	0.5
longitudinal	0.2

Table 20. Correction factor of the number of wind turbines.

Number of wind turbines	n factor
1-3	0.5
4-10	0.9
11-20	1.0
21-30	1.05
>30	1.1

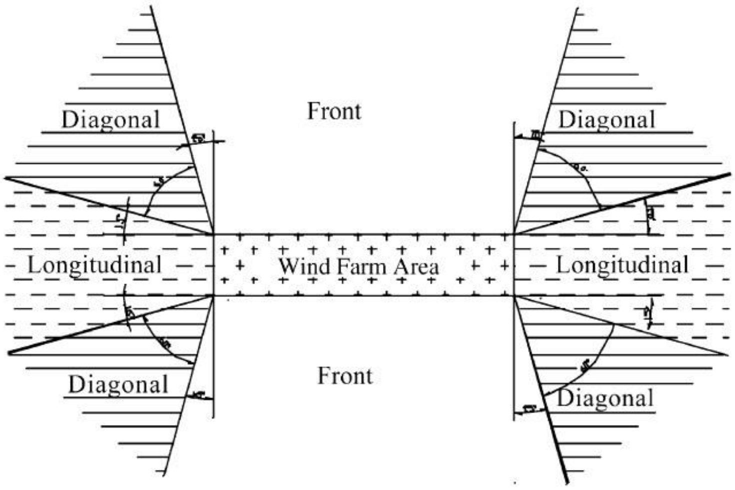

Figure 26. Wind farm's view aspect. (Hurtado et al., 2004).

d) Distance coefficient between the wind farm and the village. (Hurtado et al., 2004).

This takes into account the distance between the wind farm and the village. The distance to each village or its proximity to the wind farm is directly proportional to the alteration of the landscape. A visual influence radius is assigned to each wind turbine and a coefficient as well. For distances greater than 6000m, though the blades are still visible, the associated impact will be at a minimum, and it is possible that the wind farm could be considered part of the background landscape. See Table 21.

Table 21. Coefficient function of the distance.

X distance	d coefficient
X<500m	1.00
500<X<6000m	1.05-0.0002*x
6000m<X (if wind farm visible)	0.1

e) Population coefficient of the village. (Hurtado et al., 2004).

The visual impact increases when the number of people increases in the village, this coefficient being maximum in highly populated areas, like towns. See Table 22 of coefficient value.

Table 22. Coefficient function of population.

population	e coefficient
>300	1.00
100-300	0.90
50-100	0.60
20-50	0.45
5-20	0.35
1-5	0.20
0	0.00

Partial Evaluation. (Hurtado et al., 2004).

1. Partial assessment 1 (PA1)=a *b*c *d

2. Partial assessment 2 (PA2)=a *b* c *d *e.

According to PA1 and PA2 scores, the visual impact level can be determined, see Table 23.

In this study, the data collection process for the coefficients was as follows: for coefficient (a), we selected 10 viewpoints from each community area on the local map. Viewpoints were distributed over the whole community area, with selection made along the community's main road and significant community spots, such as JR train stations, road intersections, and shrines. At each viewpoint, we photographed visible wind turbines using a digital camera and recorded the number of visible wind turbines through site surveys on Nov 6, 2010 and Dec 5, 2010. See Figure 27 and Figure 28. For coefficient (b), we counted the number of houses on the local map and the number of visible houses from each wind farm through the above site survey. For coefficient (c), we estimated the angle factor of the wind farm base on "Wind farm and community map (Figure 19)" using AutoCAD 2008. For coefficient (d), we estimated the distance from each 10 viewpoints to each wind turbine using AutoCAD 2008 and then calculated the average distance. For coefficient (e), we used population data of 2010 from Choshi city government (2010b) for Sarudacho and Tokoyodacho.

Table 23. Determination of the impact level. (Hurtado et al., 2004)

PA	Impact Level	Description
0.00-0.10	Minimum	Installation of the wind farm does not have any impact.
0.10-0.30	Light	A decrease in the impact by means of wind farm camouflage (color and / or vegetation) is recommended.
0.30-0.50	Medium	Efforts should be made to diminish the visual impact by relocating some of the towers that are closer to human living quarters.
0.50-0.70	Serious	Part or the whole location of the wind farm should be corrected.
0.70-0.90	Very Serious	The location of the wind farm should be revised and corrected in part, or by trying to change its place.
0.90-1.00	Deep	There are no justifiable for carrying out the installation of the wind farm.

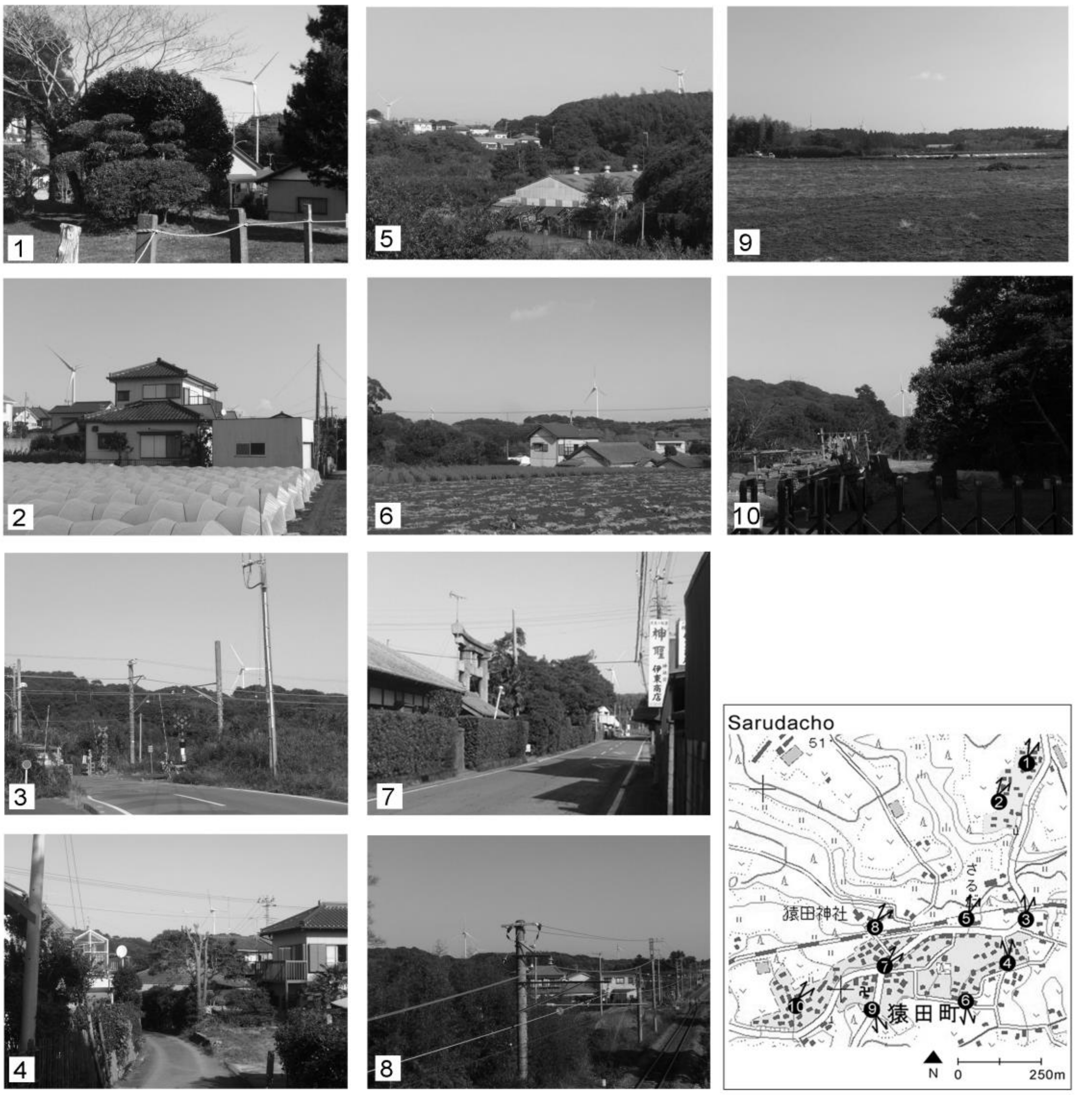

Figure 27. Picture sample for each viewpoint in Sarudacho. (Source: by author).

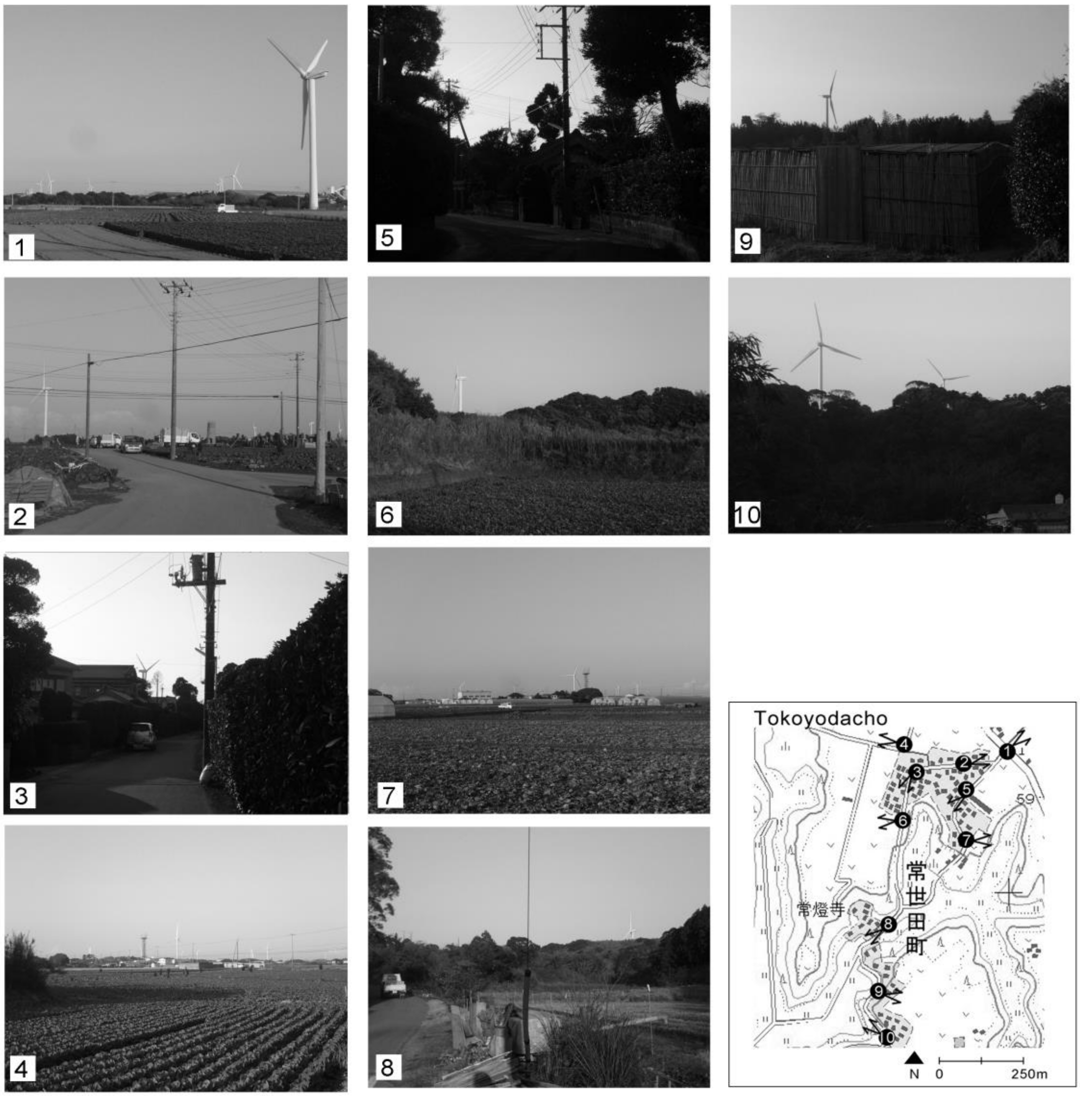

Figure 28. Picture sample for each viewpoint in Tokoyodacho. (Source: by author).

3.4.3 Questionnaire Survey.

In order to confirm the accuracy of evaluation results using the Spanish method, we conducted a questionnaire survey among the residents of Sarudacho and Tokoyodacho. Based on the consideration of households number in each settlement (Sarudacho 279 households, Tokoyodacho 66 households), we distributed a total number of 200 questionnaires on Jan 11, 2011. 140 questionnaires in Sarudacho, and 60 in Tokoyodacho. Questionnaires were hand delivered by the authors to the target communities, dropped into the mailboxes in front of each household randomly while walking around the community areas. Each questionnaire package included an explanation letter, a questionnaire sheet and mail-back envelope with a postage stamp. The explanation letter included a description of the study objectives and explanation of visual impact evaluation, to ensure uniformity on the basic understanding of study aims and questionnaire contents. The questionnaire contents were divided into four parts. 1) Respondents' basic information, 2) personal opinions on wind energy and wind farms (such as attitude, merit/demerit, and impact). 3) Respondents' visual impact evaluation of wind farms at five levels: deep, serious, medium, light, and minimum. 4) Evaluation of wind farms visual impact levels on a particular landscape scenario. We also included visual impact evaluation of different wind turbine layouts where we arranged six turbines in three layout scenarios. That is; one line, grid (two lines) and random, taking into account that there is no such coefficient provided for in the Spanish method. For landscape scenarios, five typical landscape types in Choshi city were selected including farmland, residential, urban, road, and Satoyama (forest and farmland) areas. The background picture for each landscape scenario was taken in Choshi city, and had wind turbines implanted in it using Photoshop CS2 to create five varying possibilities, see Figure 29. For layout scenarios, a general landscape background picture from the Choshi suburban area was used, and had six wind turbines implanted in it using Photoshop CS2 to create varying layouts, see Figure 30. More questionnaire sheet detail can be found in Appendix 2.

Figure 29. Photomontage for different landscape scenarios. (Source: by author).

Figure 30. Photomontage for different layout scenarios. (Source: by author).

3.5 Results

3.5.1 GIS Viewshed Analysis

GIS viewshed analysis results indicated that from 2001 to 2009, the wind turbine visible area increased along with the wind turbine numbers increase in Choshi city (see Figure 31). In 2001, when there was only one wind turbine in Choshi city, that area was 50.70km^2 (60.4% of the city area). However, by the end of 2009, the turbine visible area had increased to 78.14km^2 that covers 93.1% of the city area. Furthermore, by comparing ZVI area and wind turbine numbers from 2001 to 2009, it was found that ZVI area had increased at an average rate of 14.9% along with wind turbine numbers from 2001 to 2006. On the other hand, that rate average was only 0.9% from 2006 to 2009. The ZVI area increase rate decelerated after 2006, see Table 24.

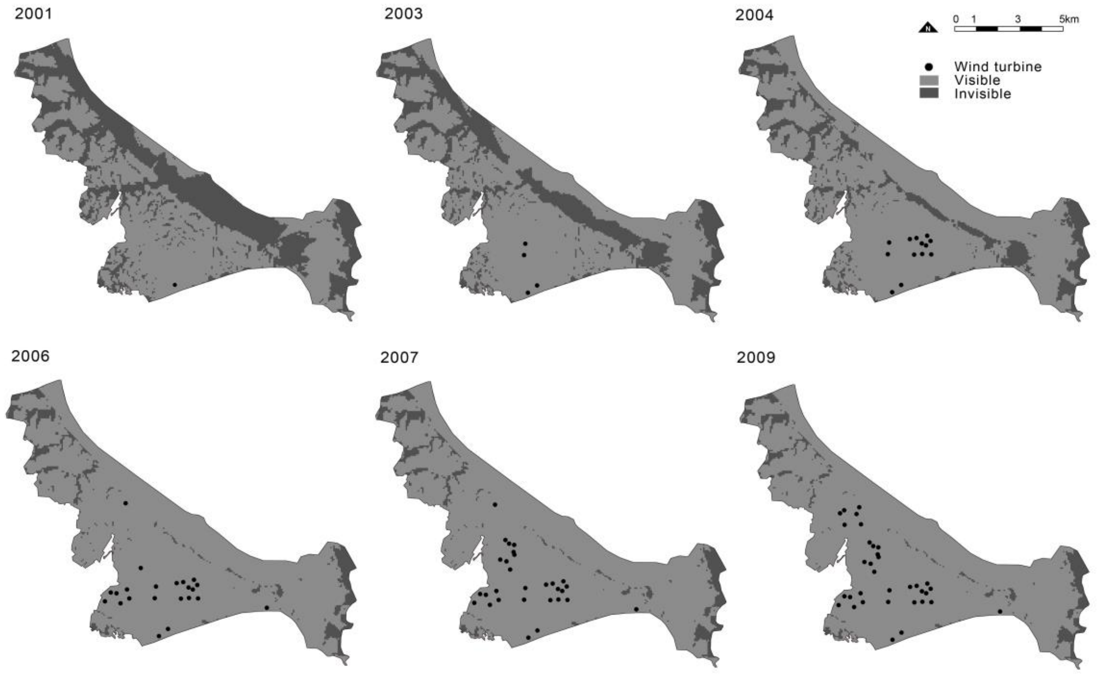

Figure 31. Wind turbine visible area change from 2001-2009 in Choshi city. (Source: by author).

Table 24. Wind turbine visible area and wind turbine numbers.

Year	ZVI (km^2)	Percentage of city area[1]	ZVI increase area (km^2)	ZVI increase rate	Total turbine number
2001	50.70	60.4%	50.7	-	1
2002	50.70	60.4%	0	-	1
2003	60.99	72.7%	10.29	+20.3%	4
2004	68.85	82.0%	7.86	+12.9%	13
2005	68.85	82.0%	0	-	13
2006	76.71	91.4%	7.86	+11.4%	22
2007	77.27	92.1%	0.56	+0.7%	29
2008	77.27	92.1%	0	-	29
2009	78.14	93.1%	0.87	+1.1%	34

[1] The city area is 83.91 km^2 in Choshi city.

3.5.2 Spanish Method

Through site survey, it is found that only three wind farms: Shiishiba, Takadacho, and Choshi wind farms were visible from Sarudacho. Thus, only the three wind farms were considered for the evaluation process in Sarudacho. Since Shiishiba and Takadacho wind farms are close to each other, we considered them as one wind farm in Tokoyodacho’s evaluation. Results from application of Spanish method in Sarudacho are as shown in Table 25, and those from Tokoyodacho are as shown in Table 26. It is found that the visual impact of wind farms was mainly in the “Minimum” levels when using the Spanish method of evaluation in the two communities.

Table 25. Evaluation results from Sarudacho

Wind farm	a	b	c	d	e	PA1	PA2	Impact Level
Shiishiba Takadocho	0.467	0.122	0.9	0.7516	1	0.039	0.039	Minimum
Choshi	0.357	0.134	0.35	0.6146	1	0.011	0.011	Minimum

Table 26. Evaluation results from Tokoyodacho.

Wind farm	a	b	c	d	e	PA1	PA2	Impact Level
Shiishiba Takadacho	0.42	0.078	0.9	0.205	0.9	0.006	0.0054	Minimum
Choshi	0.589	0.172	0.9	0.701	0.9	0.064	0.0576	Minimum
Shincho	1	0.344	1.05	0.795	0.9	0.287	0.258	Minimum
Obama	0.375	0.0625	0.25	0.637	0.9	0.0037	0.0033	Minimum
Byobukaura	0.625	0.156	0.25	0.628	0.9	0.0153	0.0138	Minimum
Shiosai	0.812	0.75	0.5	0.906	0.9	0.248	0.223	Light
Wind energy	0.6675	0.25	0.9	0.586	0.9	0.088	0.079	Minimum
Yagi	0.5	0.484	0.9	0.82	0.9	0.179	0.16	Minimum

3.5.3 Questionnaire Survey

From the 200 questionnaires distributed, the total valid responses were 63 (N=63). 44 (70%) of them were from Sarudacho and 19 (30%) from Tokoyodacho. The age of respondents varied from 40 to 80 years old. 86% of the respondents had lived for more than 10 years in the two communities. From the results, 58.7% of the respondents had a positive attitude towards wind energy and existence of wind farms near their community area. A small proportion of 11.1% of the respondents showed a negative attitude towards wind energy. The biggest impact of wind farms was on the local landscape, which scored highest, at 46.0% of the respondents. Both noise and electronic jamming came in second, at 20.6% of the respondents. Most of the respondents (88.9%) tend to tolerate less than 5 wind turbines in the landscape at the local level.

The residents' perception on visual impact level in Sarudacho and Tokoyodacho was as follows: "Deep" level 30.1%, "Serious" level 38.1%, and "Medium" level 28.6%, see Table 27. Wind turbines in residential and urban areas (close to residents' living quarters) are most likely to influence residents' perception. Among Satoyama, farmland, and road landscapes (not very close to residents' living quarters), wind turbines had a higher impact level on Satoyama than that of farmland and road areas, see Table 28. In comparative consideration of wind turbines layouts, respondents indicated that one line layout had the strongest visual impact on the landscape. They ranked it as follows: "Deep" level 44.4%, "Serious" level 34.9%, and "Medium" level 19.0%. Unlike one line layout where the majority ranked it as "Deep" level, the grid (two lines) layout was ranked by the majority in "Serious" level. Its ranking distribution was as follows: "Deep" level 22.2%, "Serious" level 42.9%, and "Medium" level 30.1%. On the other hand, the majority ranked the random layout in the "Medium" level. The ranking was; "Deep" level 17.5%, "Serious" level 30.1%, "Medium" level 34.9%, and "Light" level 15.9%, see Table 29.

Table 27. Impact levels of wind turbines to local landscapes (N=63)

Settlement	Deep	Serious	Medium	Light	Minimum	Total
Sarudacho	13	17	12	0	2	44
Tokoyodacho	6	7	6	0	0	19
Total	19	24	18	0	2	N=63
Percentage	30.1%	38.1%	28.6%	0	3.2%	100%

Table 28. Evaluation of results of different landscape scenarios (N=63)

Landscape	Deep	Serious	Medium	Light	Minimum
Residential	25	19	17	1	1
Urban	15	23	23	1	1
Satoyama	13	15	28	2	5
Farmland	8	24	23	1	7
Road	7	22	27	3	4

Table 29. Evaluation results of different layout scenarios (N=63)

	Deep	Serious	Medium	Light	Minimum
One line	28	22	12	0	1
Grid(2 line)	14	27	19	2	1
Random	11	19	22	10	1

3.6 Discussion

According to the methodology, this study applied a shallow Viewshed analysis for visual impact evaluation at the city level. This was due to lack of GIS data on buildings and vegetation heights and distribution. The overall understanding of the visual impact of wind farms to a city is also too complicated. Therefore, we did not analyze all the shielding of wind turbines by buildings or tree canopies. By the end of 2009, at least one wind turbine was visible from 78.14km^2 (93.12%) of Choshi city. Although ZVI area increased at a higher rate of 14.9% from 2001 to 2006, it just increased at a minimal rate of 0.9% during 2006 to 2009. This could be due to the covered influence area with each wind turbine under local topographic conditions.

After comparison of Spanish method results (Table 25 and Table 26) to those from the questionnaire survey (Table 27) of visual impact level, we found out the following. According to Spanish method results, the impact levels were mainly “Minimum” or “Light”. In the questionnaire survey, the impact levels were mainly “Deep”, “Serious”, and “Medium”. There is a disparity between the two evaluation methods as revealed by the difference in results. The results of visual impact levels of wind farms to residents perception according to the questionnaire result is deeper than the level revealed by the Spanish method. This study got different results to those of the research done in Crete island in Greece by Tsoutsos et al. (2009), where the use of Spanish method for visual impact evaluation was successful because its outcome corresponded to those obtained from public opinion survey. The difference between Spanish method results and questionnaire survey results in this study could be due to the following four reasons. 1) Spanish method only supports one wind farm for one settlement evaluation. It cannot evaluate the cumulative impacts to one settlement surrounded by multiple wind farms, as in the case of Tokoyodacho. 2) Because European researchers developed the Spanish method, the coefficient calculation method and evaluation criteria may be only suitable for Spain or Europe, as opposed to Japan or Asia due to geographical and social context. 3) Uncertainty of data may result from coefficients data collection process such as recording of visible wind turbines numbers. 4) Personal perceptions may also vary due to a wide range of reasons.

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CHAPTER 4

A GIS BASED APPROACH OF SPATIAL PLANNING FOR RENEWABLE ENERGY

"A GIS-Based Approach to Supporting Spatial Planning of Renewable Energy: a Case Study of Fukushima, Japan"

Published at: *Sustainability. 6(4), 2087-2117.*

4.1 Introduction

Renewable Energy (RE) is receiving increasing attention for its clean, green, safe characteristics. It is driving energy structure towards a sustainable level by providing a sustainable approach to energy generation (Elliott, 2000; Vera and Langlois, 2007), and contributing to mitigation of the greenhouse effect in the long term (Dincer, 2000). It also plays a vital role in the overall sustainable development strategy (Dincer, 2000; European Renewable Energy Council, 2012). The spatial distribution of Renewable Energy Sources (RES) is strongly affected by geographic and topographic factors such as altitude, climate, and terrain conditions (Vettorato, 2011). Thus, exploration and supply of RE take place at the local or regional levels (Sarafidis, 1999; Voivontas et al., 1998). These features also shape RE supply distribution networks in decentralized forms, consequently making the planning of RE concentrated on a detailed scale.

Geographic Information Systems (GIS) have proved a useful tool for regional RE potential estimation (Hoesen and Letendre, 2010; Gil et al., 2011; Arnette and Zebel, 2011) and as support for decision making in energy planning (Voivontas et al., 1998; Clarke and Grant, 1996; Domingues and Amador, 2007). This is due to their flexible data management and spatial-temporal analysis capabilities. Furthermore, the visualization function of GIS can connect statistical analysis with visualized spatial data in the integrated RE planning approach. Such visualization maps make planning easier to understand for policy makers, private investors, and citizens. It also provides a platform for information sharing and planning participation through Web-based GIS (Simao et al., 2009; Bayern Gov., 2014).

At the regional level, several traditional techniques have been applied in RE planning. These include Multiple-Criteria Decision Analysis (MCDA) (Geogopoulou et al., 1997; Beccali et al., 2003; Pohekar and Ramachandran, 2004; Loken, 2007; Tsoutsos et al., 2009; Terrados et al., 2009), Delphi surveys (Shiftan et al., 2003; Czaplicka-Kolarz et al., 2009; Celiktas and Kocar, 2010), and the participatory approach (Neudoerffer et al., 2001). There are also a few methodologies and empirical studies on RE planning in literature. Terrados et al. (2009) proposed a combined methodology for RE planning; a hybrid composed of SWOT analysis, MCDA, and Delphi methods. Sarafidis et al. (1999) 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 (2006) introduced a framework and several tools to help in building a renewable energy system at the city scale. Among European municipalities, an aim to achieve 100% energy self-sufficiency through RE supply has been a common trend in planning practice. Some of them such as Mauenheim (Germany) and Gussing (Austria) have achieved or will achieve energy autonomy in the coming decade (Takigawa et al., 2012). Nevertheless, RE planning application has often been limited to the district (Portland Sustainability Institute, 2014), community, or city scale (Stremke and Koh, 2010). Previous research has focused on estimation (Voivontas et al., 1998; Yue and Wang, 2006; Hoesen and Letendre, 2010; Gil et al., 2011; Arnett and Zebel, 2011) and mapping (Ramachandra and Shruthi, 2007) 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 (Japanese Ministry of Economy, Trade and Industry, 2010). 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 an attempt to accelerate the RE's development in Japan, the Feed-in Tariff (FIT) for RE was announced and started in July, 2012. As the prefecture most affected by the nuclear crisis, the Fukushima local government has realized the urgent need to develop clean, green, and safe RE to drive its energy structure into a safer, more self-sufficient state. 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 proposes a GIS-based integrated approach in order to estimate energy self-sufficiency possibility at the regional level, based on primary energy consumption and available RE potential estimation. It aims 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 including; primary energy consumption estimation, renewable energy potential estimation, energy self-sufficiency analysis, composite map preparation, and scenario analysis using GIS. This approach takes a step away from previous works that only dealt with GIS-based RE potential estimation or site selection by taking into account the future of energy self-sufficiency possibilities, multiple RES potential sites analysis, and scenario analysis at the regional level using GIS. This study has 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. This approach was applied to Fukushima Prefecture as a case study, because of the planning needs for the 2020 and 2030 RE development vision for 2020 and 2030. GIS was used to analyze solar, wind, biomass, geothermal, and hydro-power potential within Fukushima Prefecture, Japan. Potential sites were determined based on geographic, topographic, and land use constraints. Evacuees' population and forest radiation levels are specifically considered in the context of radiation emanating from the Fukushima Daiichi Nuclear Crisis.

The proposed approach may help with decision-making in support of the RE planning process, through the provision of visualized and quantified information on regional potentials and restrictions to different energy stakeholders such as the energy policy makers and local authorities. This could help to build an energy development vision, driving regional energy development towards sustainability. Moreover, the approach presented in this study could serve as an example applicable in other Japanese municipalities to help in building a safer, sustainable energy system. This case study provides an example on how to establish local GIS databases through the utilization of various online open GIS resources in Japan.

4.2 Proposed Approach

We propose an integrated information approach for decision-makers in support of RE spatial planning at the regional level, with a goal 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) Scenario analysis.

(6) Decision making support in RE planning.

The procedure to implement the proposed approach is described step by step from Sections 4.4.1–4.4.6. Figure 32 shows the illustration of the approach framework.

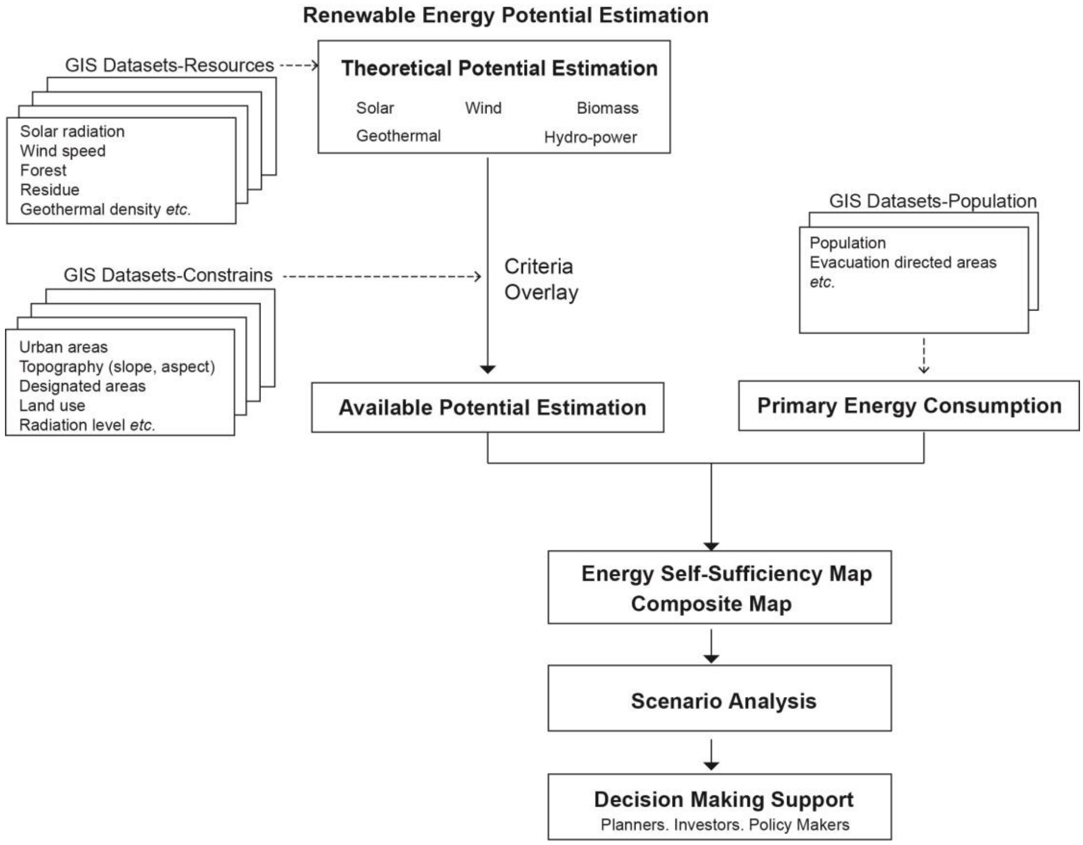


Figure 32. Framework of proposed approach. (Source: by author).

4.3 Application of Proposed Approach: a Case Study of Fukushima, Japan

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 to east, they order (1) the Aizu region that includes Aizu and Minami Aizu areas; (2) the Naka-doori region that includes Kenpoku, Kenchu, and Kennan areas; and (3) the Hama-doori that includes Soso and Iwaki areas. The 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 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, the Fukushima Government is currently putting efforts into RE development. This was one of the approaches for post-earthquake reconstruction. From 2009–2020, the government had 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 (Fukushima Gov., 2012).

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. GIS data for all the RE facilities in Fukushima was incomplete, hence we gathered their details (capacity, year among others) from different resources. This includes wind (NEDO, 2013), solar PV mega-solar (Fukushima Gov., 2013; Electric Japan, 2013), biomass (Fukushima Gov., 2013), hydro-power (Electric Japan, 2013; Fukushima Gov., 2013), geothermal (Fukushima Gov., 2013), biofuel (Fukushima Gov., 2013), and natural gas co-generation (Fukushima Gov., 2013). Point data was created for current RE facilities in GIS. A grid and substation map based on information from online RE potential database provided by Fukushima Government (Fukushima Gov., 2013) was also derived. Figure 33 illustrates different regions, as well as power plants and grid in Fukushima prefecture. See more detail of current RE facilities in Fukushima in Appendix 8.

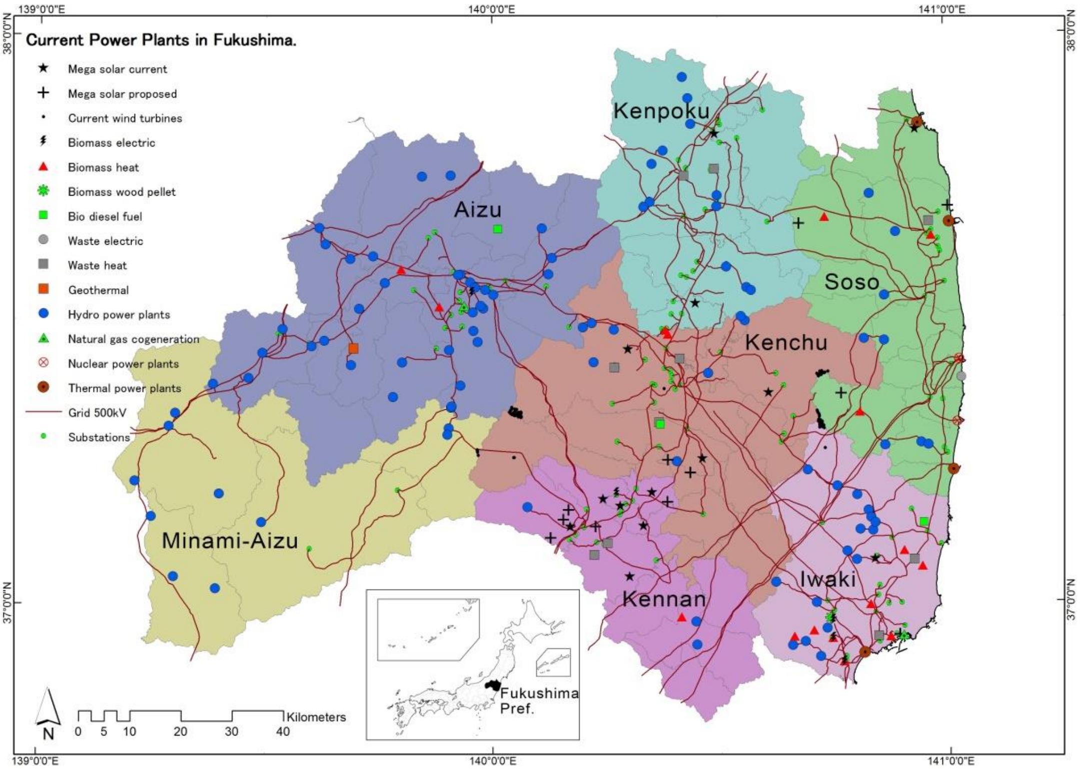


Figure 33. Regions, power plants, and gird network in Fukushima. (Source: by author).

4.4 Methods and Datasets

4.4.1 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. Primary energy consumption was chosen because of the 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 30.

Table 30. Japan Primary Energy Consumption and Population in 2010, 2020, and 2030.

Japan	2010	2020	2030
Total Primary Energy Consumption (IEA, 2010)	501 Mtoe [(1)]	491 Mtoe	482 Mtoe
Total Population (IPSS, 2013)	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 (Japan Government Statistics, 2013). The population data is contained in sub-municipal (small regions that constitute one municipality) level, see Figure 34. The original data for each municipality in Fukushima was downloaded, and then merged all the municipalities' data into one Fukushima prefectural population data using ArcGIS 10.1 (herein referred to as GIS).

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 (Japan Ministry of Education, Science and Culture, 2011). 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 (Japan Ministry of Education, Science and Culture, 2011).

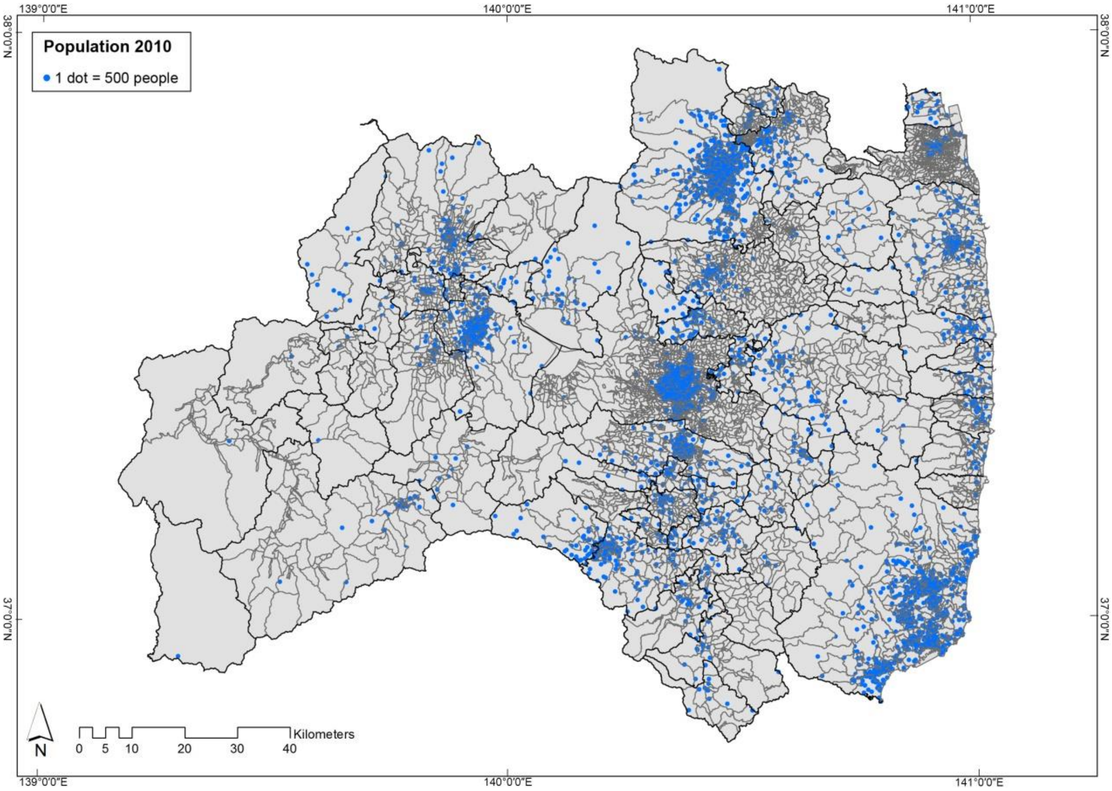


Figure 34. Fukushima population (2010) presented by dot density. (Source: by author).

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) (Japan Ministry of Land, Infrastructure, Transport and Tourism, 2013). In this study, for the difficult to return zone, we assumed that 0% of the residents will return by 2020 ((Japan Ministry of Land, Infrastructure, Transport and Tourism, 2013) and that 20% of the residents will return by 2030. For the habitation restriction zone, this study has 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 (Fukushima Gov., 2013).

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 (IPSS, 2013). Fukushima's population by 2020 and 2030 has been calculated based on the above rates of decrease. The primary energy consumption has been calculated based on this population prediction. The results have been consequently converted 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.

This study used Japanese Mesh System that has uniform geographic position and specific mesh ID (Biodiversity center of Japan, 2013). In this way, uniformity of mesh position for further GIS analysis has been insured. The mesh system is in five mesh levels (Japan Government Statistics, 2013). 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.

4.4.2 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 solar, wind, biomass, geothermal, and hydropower 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 (Voivontas et al., 1998). 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.

- 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 (Japan Ministry of Land, Infrastructure, Transport and Tourism, 2013), see Figure 35. We calculated the solar potential within a new field using the Field Calculator as follows (NEDO, 2012):

$$S_t = S_1 \times 365 \times S_2 \times \eta$$

where *St* 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% (Japan Ministry of Environment, 2009).

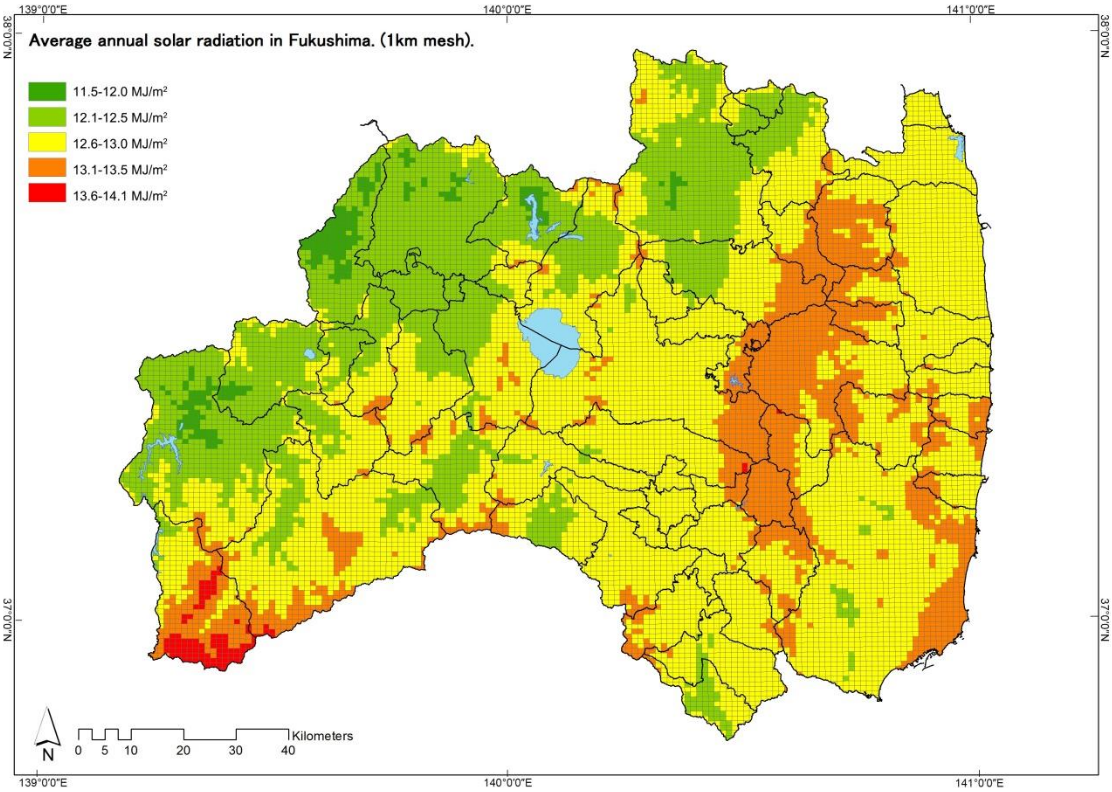


Figure 35. Average annual solar radiation in Fukushima (1km mesh).

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 (Arnette and Zebel, 2011).

- ✓ Exclude superior agricultural areas, protected forest areas, natural preservation areas, national parks (special preservation area), and landslide areas assigned by relative laws in Japan (Japan Ministry of Environment, 2009).
- ✓ 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 (Japan Ministry of Environment, 2009).
- ✓ Minimum available land area of 1.5 ha (Fukushima Gov., 2013).

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 (2013). 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 (2013).

- Wind Energy

Only 500 m mesh wind speed data (at the height of 70 m, with geographic coordinates) in ".dat" format (NEDO, 2013) have been found. 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 36. 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 (Kitakata city Gov., 2008):

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

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 (10D) apart based on wind flow and turbine efficiency consideration. Thus, one wind turbine at least takes about an area of $(10D)^2$. F can be calculated by the total geographic area divided by $(10D)^2$.

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 (Sarafidis et al., 1999; Voivontas et al., 1998).
- ✓ Altitude < 1000 m (Sarafidis et al., 1999; Voivontas et al., 1998; Hoesen and Letendre, 2010; Japan Ministry of Environment, 2009).
- ✓ Slope < 20 °(Japan Ministry of Environment, 2009).
- ✓ Non-urbanization area (Japan Ministry of Environment, 2009).
- ✓ 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 (Japan Ministry of Environment, 2009).
- ✓ Buffer distances: cities and towns > 2000 m (Baban and Parry, 2001), villages > 500 m (Baban and Parry, 2001; Japan Ministry of Environment, 2009; Silz-Szkliniarz and Vogt, 2011), water bodies and wetlands > 500 m (Arnette and Zebel, 2011), ecological sensitive areas > 1000 m (Baban and Parry, 2001; Arnette and Zebel, 2011), airports > 2500 m (Voivontas et al., 1998), historical areas > 2000 m (Voivontas et al., 1998; Baban and Parry, 2001; Silz-Szkliniarz and Vogt, 2011).
- ✓ 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 (Japan Ministry of Environment, 2009).

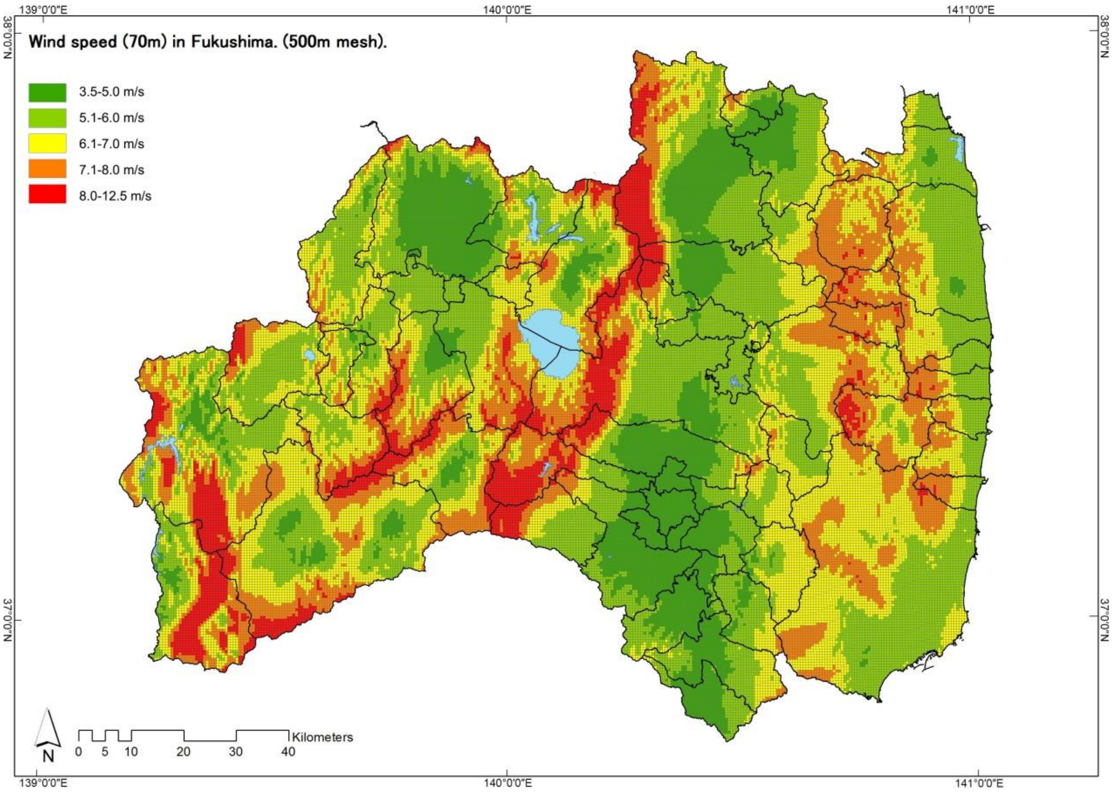


Figure 36. Wind speed in Fukushima (500m mesh, at the height of 70m). (Source: by author).

GIS resources used were Fukushima municipal boundary, topography, designated areas, and land use datasets, the same we used for "Solar Photovoltaic" potential estimation. 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) (2013).

- 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 (2013), which include annual forest growth data in Japanese standard 1 km mesh, see Figure 37. Then, the potential of wood biomass was estimated within a new field using the Field Calculator based on the following equation (NEDO, 2012):

$$\mathrm{Q} = \mathrm{S} \times 500 \times \mathrm{C} \times \eta$$

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% (Japan Ministry of Economy, Trade and Industry, 2013).

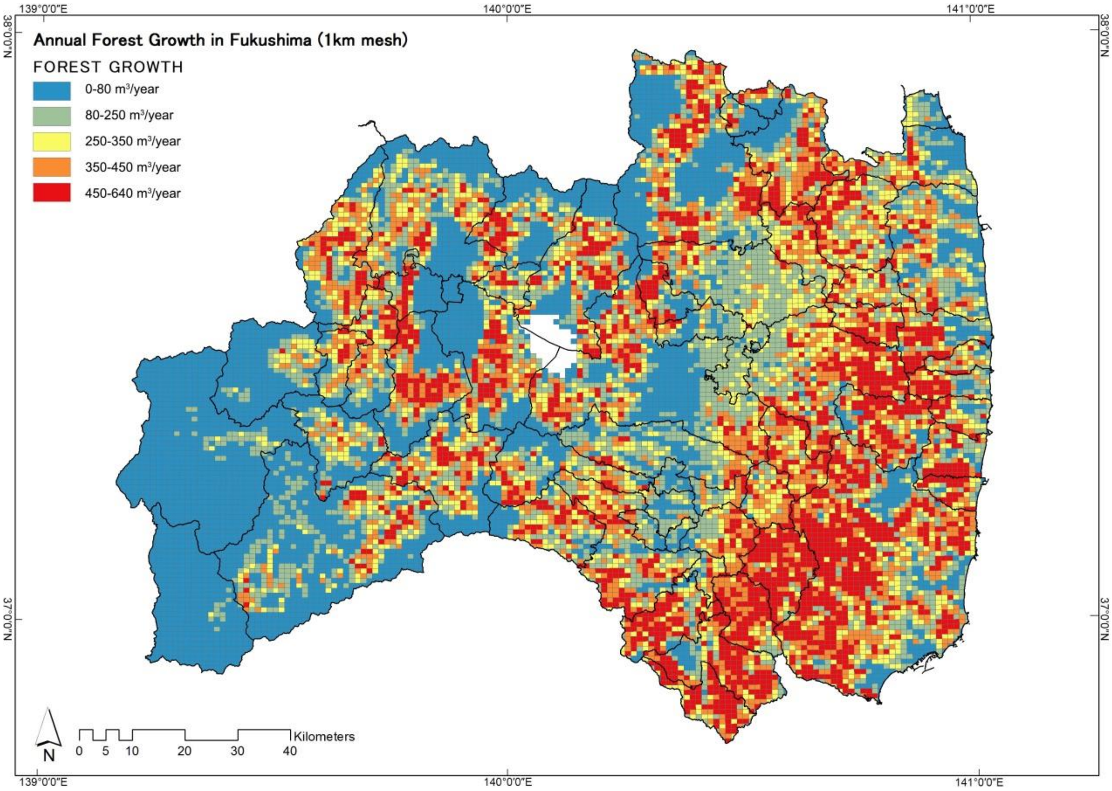


Figure 37. Annual forest growth rate in Fukushima (1km mesh). (Source: by author).

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% (Hoesen and Letendre, 2010; Verrorato et al., 2011).

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 100Bq/kg (Fukushima Gov., 2013). In the meantime, Forestry Agency's study (Forest Agency, 2013) has shown that a forest with an air dose level (1 m above ground) of 0.3μSv/h has about 7000Bq/kg contained in leaves, about 980Bq/kg in tree bark, and about 12Bq/kg in timber. While in a forest with an air dose level (1 m above ground) of 0.12μSv/h, the number decreases to about 990Bq/kg in leaves, 300Bq/kg in tree bark, and 8Bq/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 308Bq/kg when the air dose level is 0.12μSv/h in the forest. Therefore, in this study, we proposed additional criteria for selecting the available forests in Fukushima as follows.

- ✓ Air dose rate (1m above ground) < 0.1μSv/h

We obtained monitoring information of environmental radiation levels from Nuclear Regulation Authority for Fukushima (Nuclear regulation authority, 2013). 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:

$$N_t = N_0 \times 0.5^{\frac{t}{T}}$$

where *Nt* 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, their composite radiation level was calculated using the following equation (Nuclear Regulation Authority, 2012):

$$\mathrm{R} = \mathrm{Cs134} \times 70\% + \mathrm{Cs137} \times 30\%$$

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 (November 5, 2011) and 6th (November 16, 2012) airborne monitoring results, there is an additional natural decay rate of 15% per year (Nuclear regulation authority, 2013), 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 (Fukushima Gov., 2013), 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. 100 m resolution was chose to be consistent with the following geothermal density raster map's resolution (100 m, provided by Japanese

Ministry of Environment). We subsequently extracted those areas that would have less than 0.1μSv/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 (Ramachandra and Shruthi, 2007). We obtained residue biomass data at both 1 km mesh and municipal level from NEDO (NEDO, 2013). 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/year by NEDO, thus we did not conduct available potential estimation for them. See Figure 38-43 for residue biomass theoretical potential maps.

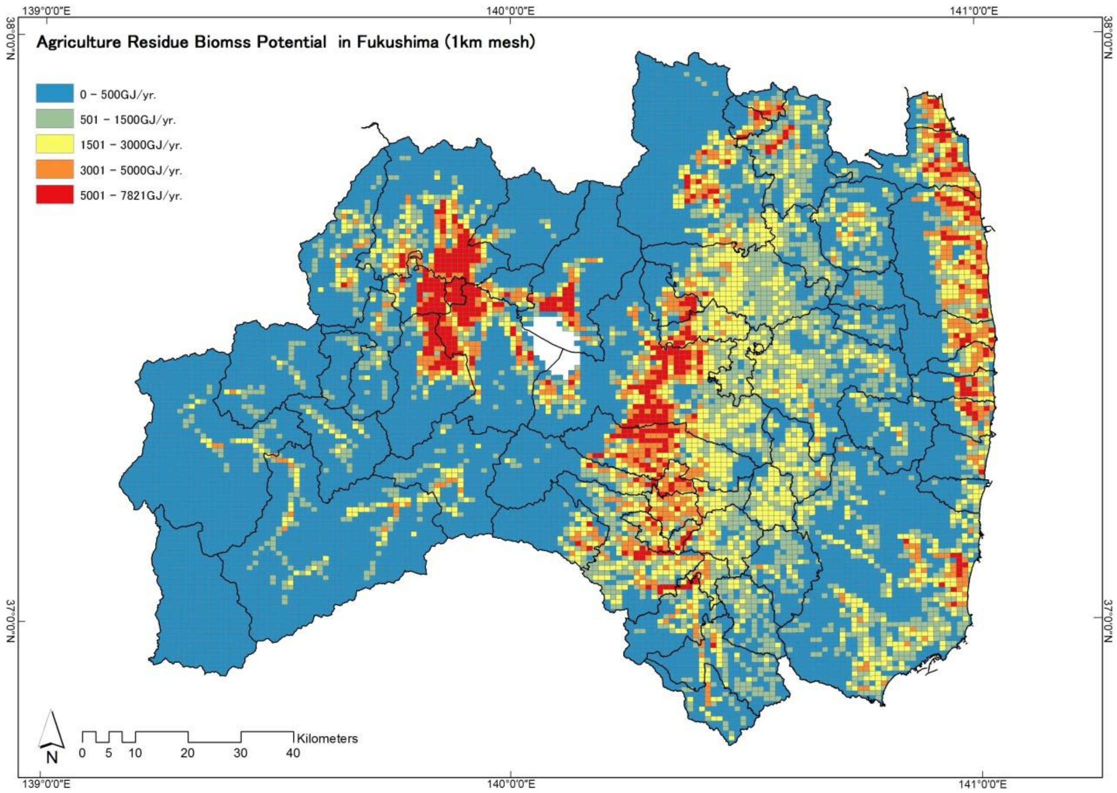


Figure 38. Agriculture residue theoretical potential. (Source: by author).

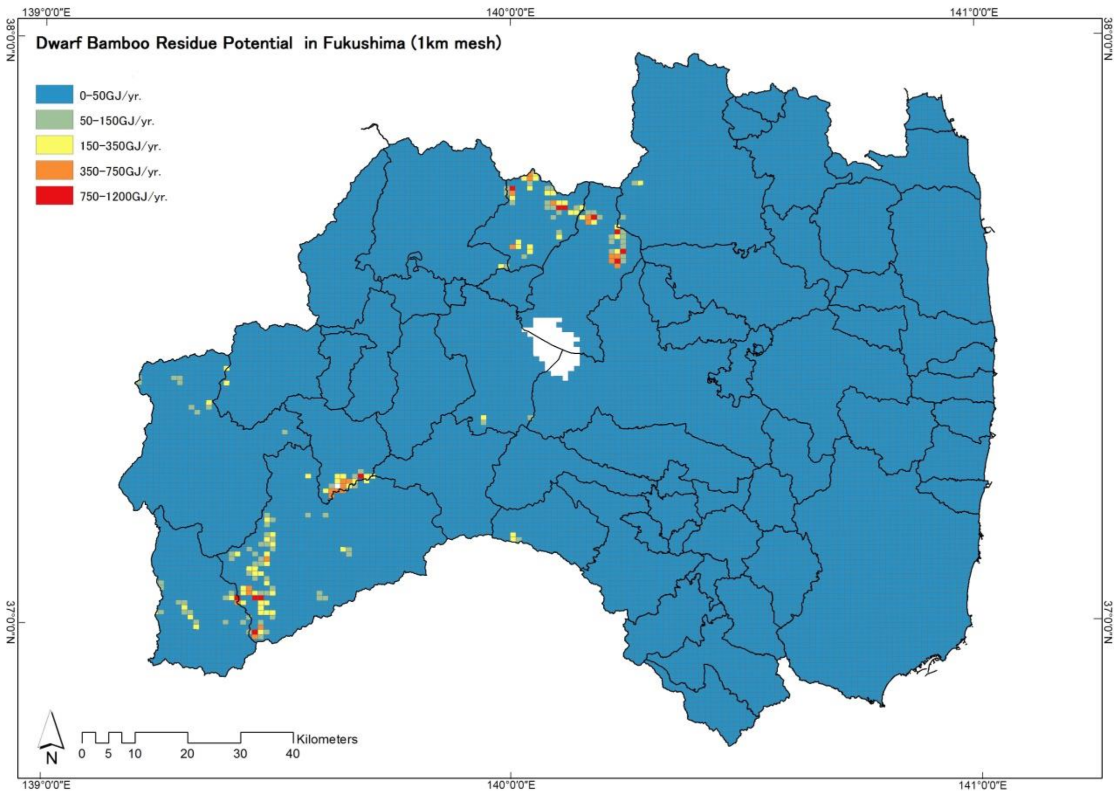


Figure 39. Dwarf bamboo residue theoretical potential. (Source: by author).

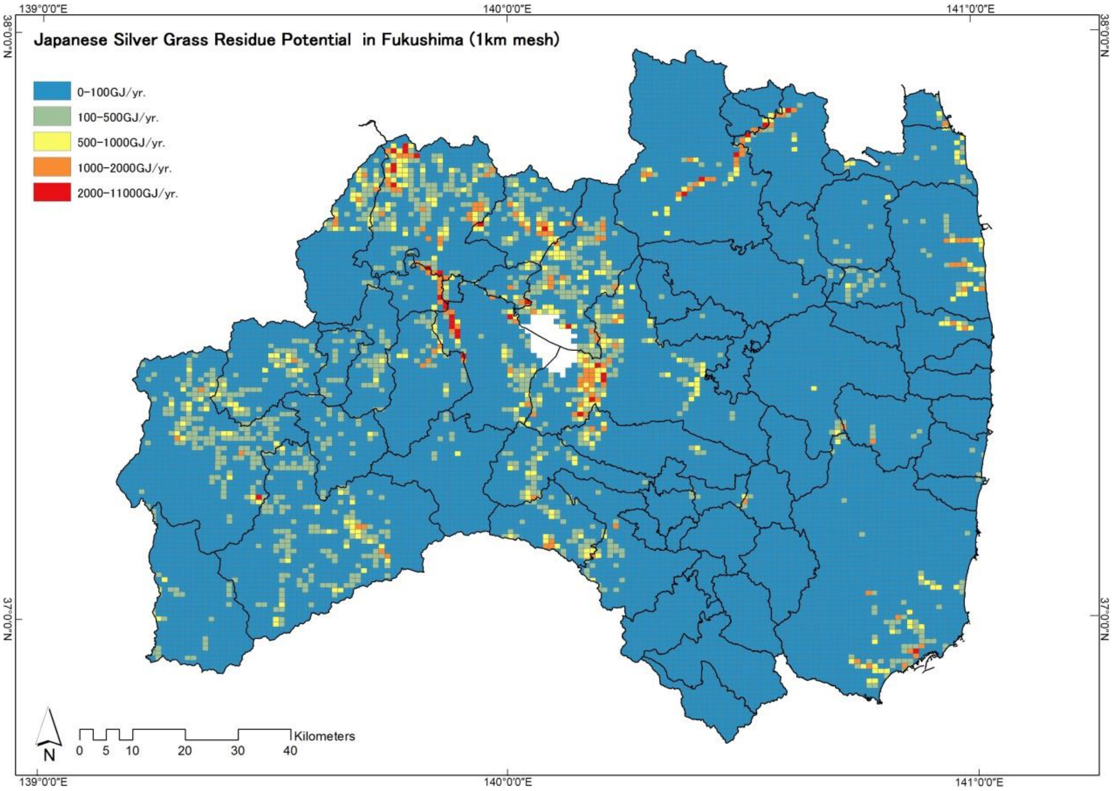


Figure 40. Japanese silver grass residue theoretical potential. (Source: by author).

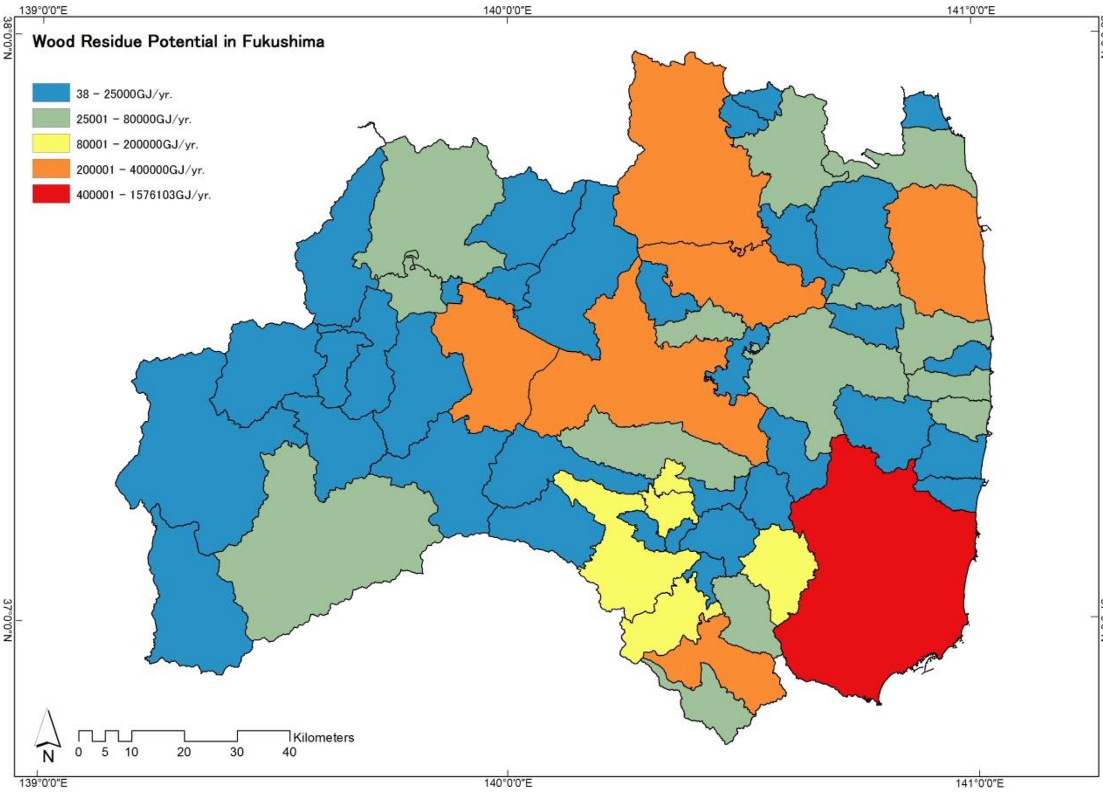


Figure 41. Wood residue theoretical potential. (Source: by author).

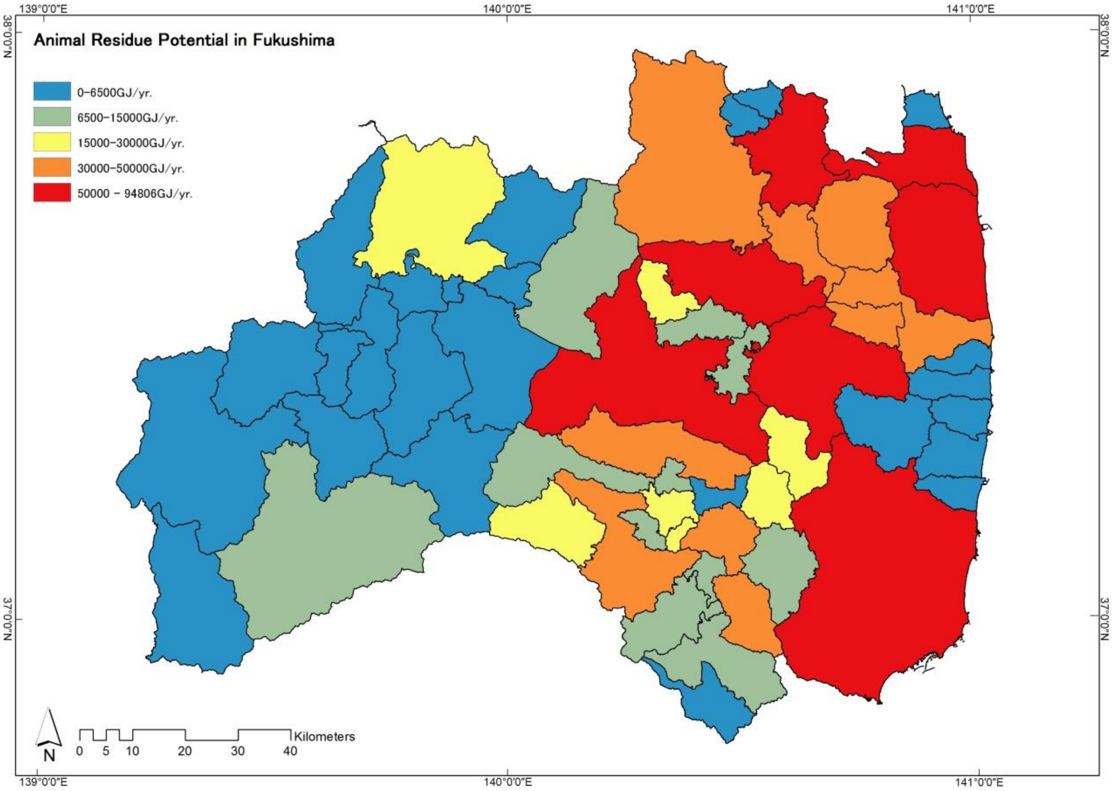


Figure 42. Animal residue theoretical potential. (Source: by author).

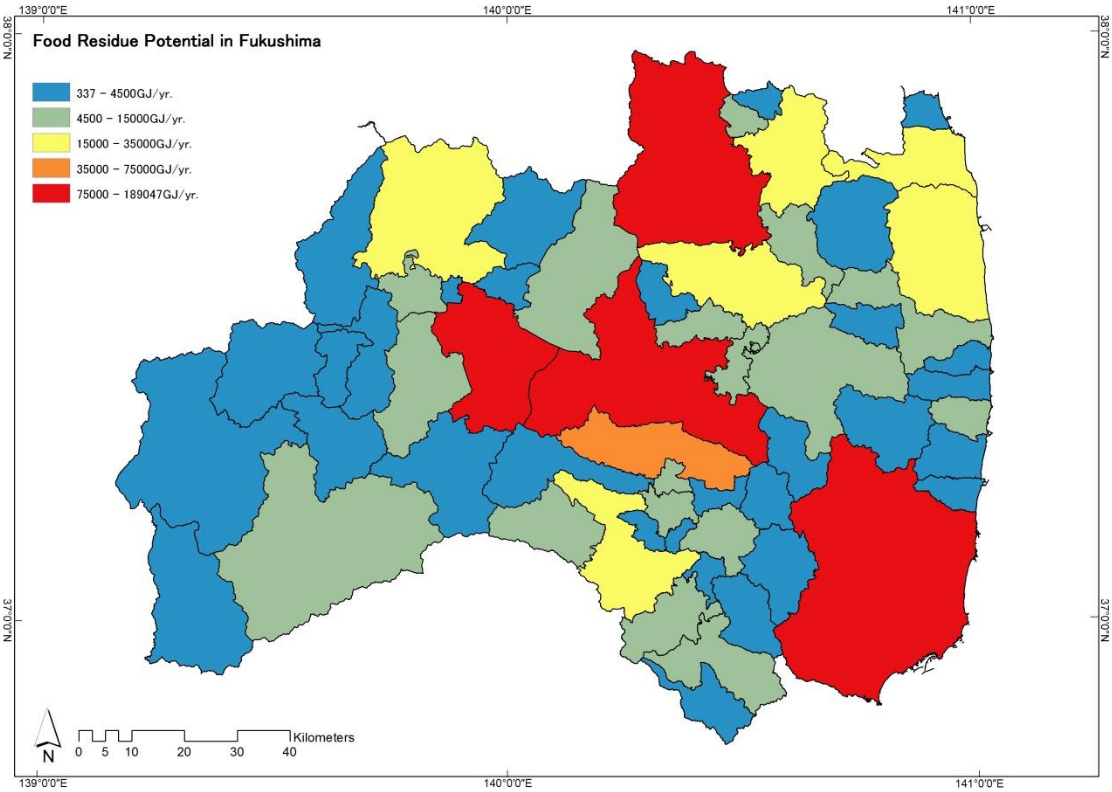


Figure 43. Food residue theoretical potential. (Source: by author).

We used the same data that include Fukushima municipalities' boundaries, topography, designated areas, and land use datasets as we used for "Solar Potential" estimation. Data relative to vegetation and the forest was as follows. The fifth vegetation survey (polygon, 1:50,000) (Biodiversity center of Japan, 2013), forest growth (polygon, 1 km) (NEDO, 2013), residue biomass (polygon 1 km; in the form of ".xls" file, converted to ".dbf" format to update GIS polygon data as mentioned above) (NEDO, 2013), and radiation levels data obtained from Nuclear Regulation Authority (2013).

- 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 (Verrorato et al., 2011). We obtained geothermal density raster map (resolution 100 m) from Basic Zoning Information (2012) of RE by Japanese Ministry of Environment (Japan Ministry of Environment, 2012). 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 44. We then estimated geothermal potential within a new field using the Field Calculator based on the following equation:

$$\mathrm{Q} = G_{\rho} \times S \times 8760 \times \eta$$

where Q is the geothermal potential in kWh/year, $G\rho$ is the geothermal density in kW/km^2, S is the land area in km^2. The total hours in one year are 8,760, while η is the energy efficiency factor of geothermal power plant; we set η as 70% (Japan Ministry of Economy, Trade and Industry, 2013). Temperatures above 50 ℃ are applicable for geothermal exploitation, but high-temperatures (>150 ℃) are needed for large geothermal power plants. An empirical case has shown that low-temperatures geothermal (about 50–120 ℃) is possible for district heating. 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 ℃ (Japan Ministry of Environment, 2009; Ostergaard and Lund, 2011).
- ✓ 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 (Japan Ministry of Environment, 2014).
- ✓ Land area size >0.5 ha (Japan Ministry of Environment, 2014).

We used the same data that include Fukushima municipalities' boundaries, topography, designated areas, and land use datasets as we used for "Solar Potential" estimation. Geothermal density map (>53 ℃) was obtained from Basic Zoning Information (Japan Ministry of Environment, 2012) in raster data format.

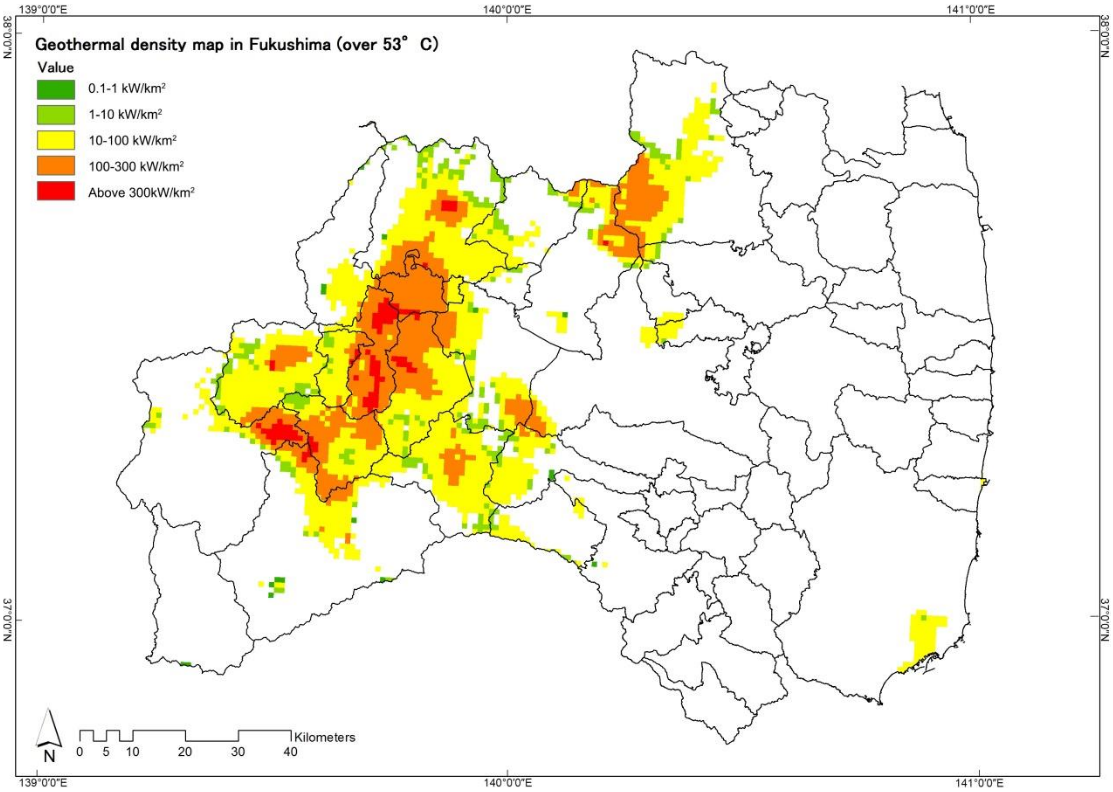


Figure 44. Geothermal density map in Fukushima (over 53 ℃). (Source: by author).

- 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 of RE by the Ministry of Environment (2012), see Figure 45. We used the following equation to estimate hydro-power potential within a new field using the Field Calculator:

$$Q = W \times 8760 \times \eta$$

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% (Fukushima University, 2013).

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 (Kiryu City Gov., 2014). We used the same data that include Fukushima municipalities' boundaries, topography, designated areas, and land use datasets as we used for "Solar Potential" estimation. A mini and micro hydro-power output potential map was derived from hydro-power potential map (Japan Ministry of Environment, 2012).

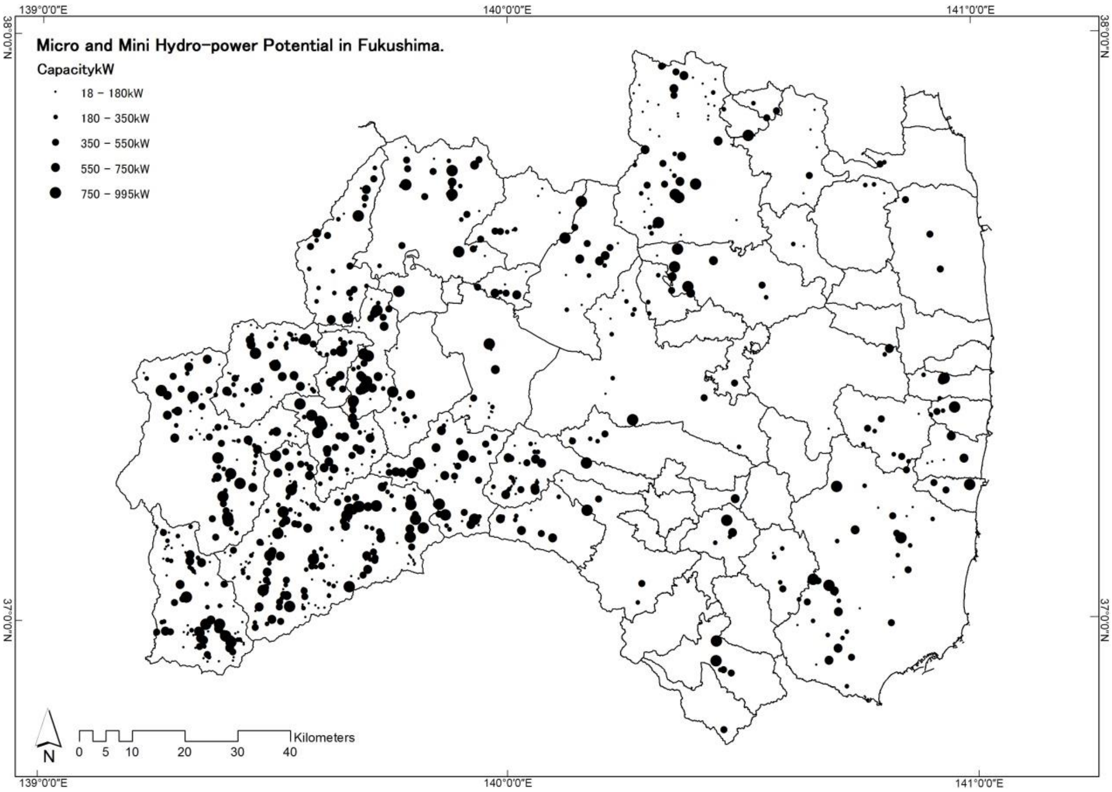


Figure 45. Mini and micro hydro-power output potential in Fukushima. (Source: by author).

4.4.3 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 31 for data processing procedure and tools used. In this study, it is 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. Areas were classified 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.

4.4.4 Composite Map Preparation

In spite of the final self-sufficiency mesh map, the available potential vector maps generated in potential estimation process for each RES can also be used to identify suitable sites under various environmental and socio-economic constraints. After overlays with different criteria, available potential vector maps for mega-solar, wind, forest, geothermal, and hydro-power based on inter-output data were generated (see Table 31). 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, the current RE facilities in Fukushima were included into the map. Heat cannot be transferred through long distances; its maximum transferable distance is about 10 km (Stremke and Koh, 2010). 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, the boundaries for evacuation-directed zones and hatched urban areas were added in the composite map.

Table 31. Data processing procedure and tools used in the 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.

4.4.5 Scenario Analysis

The scenario analysis was conducted at both regional level and municipal level. At the regional level, we assumed Fukushima's RE promotion Vision (solar energy, 1000MW; wind energy 2000MW; hydropower 3980MW; biomass electricity 360MW; and geothermal 65MW) (Fukushima Gov., 2012) for 2020 will be completed at different levels. Thus, we set three scenarios, they are: a high objective scenario in which the goal would be completed at 100%; a medium objective in which the goal would be completed at 80%; and a low objective where the goal will be completed at 50%. The number of RE facilities that need to be built in the future was calculated by dividing total increased capacity by the average capacity of an RE facility (average capacity: Mega-solar, 1.5MW; wind farm, 46MW; mini and micro hydro-power, 0.538MW; biomass-electricity, 12.3MW; geothermal 65MW).See Table 32.

Table 32. The capacity and number of RE facilities that increase to achieve the goal in different scenarios.

	Fukushima's RE facility capacity in 2009	**Scenario-1 High** RE facility capacity that increase to complete 100% of the 2020 goal (Number of RE facilities)	**Scenario-2 Medium** RE facility capacity that increase to complete 80% of the 2020 goal (Number of RE facilities)	**Scenario-3 Low** RE facility capacity that increase to complete 50% of the 2020 goal (Number of RE facilities)
Solar	38.9MW	961.1MW (641)	769MW (513)	480.5MW (320)
Wind	69.9MW	1930.1MW (42)	1544MW (36)	965MW (21)
Hydropower	3973MW	7MW (13)	5.6MW (10)	3.5MW (6)
Biomass-electricity	66.4MW	293.6MW (24)	191.7MW (16)	146.8MW (12)
Geothermal	65MW	2MW (1)	1.6MW (1)	1MW (1)

Under different scenarios, based on the increase in number of RE facilities, we selected out a respective number of available sites for each RES by their high potential (GJ) ordering in GIS. Then we added different layers in one data view for each scenario using GIS. Based on the exported scenario maps from GIS, we traced those high potential zones for completing the 2020 goal under different scenarios using Adobe Illustrator CS6.

For better decision making support and to provide specific quantified data of each scenario, we used four factors to compare three scenarios. They were construction costs, electricity production/year, number of single family homes supplied, and CO_2 reduction amount. For construction cost calculation, the following units were used. Mega-solar, 300,000 JPY/kW; wind turbine, 300,000 JPY/kW; Mini and micro hydro-power, 3540,000 JPY/kW; biomass-electricity, 410,000 JPY/kW; and Geothermal 1,000,000 JPY/kW. Annual electricity production was calculated by RE facility capacity multiplied by the total number of hours in one year and the RE facility's energy efficiency factor (solar, 12%; wind 20%; biomass electricity 20%; hydro-power 50%; geothermal 70%). Income of electricity sold was calculated based on the Japanese FIT price (Mega-solar, 32JPY/kWh; wind, 22JPY/kWh; biomass-electricity, 24JPY/kWh; hydro-power, 21JPY/kWh; and Geothermal, 40JPY/kWh). Average electricity consumption per family, 5500kWh, was used in the calculation for single family homes supplied. For the CO_2 reduction amount, we used a CO_2 reducing factor at 0.58kg/kWh of electricity (Yue and Wang, 2006).

At the municipal level, we only conducted a preliminary study for scenario analysis, because of the uncertain percentage of retuning evacuees' in the future. Kawamata town was selected because it has the greatest number of new public houses at the town level, and also has evacuation zones within the boundary. Based on a regional level composite map, we clipped available areas of each RES with the Kawamata boundary in GIS. Consequently, an integrated potential map that clarifies available RE potential in Kawamata town was generated.

We then coded all the available sites for each RES and summarized their information. For mega-solar sites, we summarized the information for average annual solar radiation, land use, aspect, slope, area, annual electricity production, access, land use regulation, and inside evacuation zones or not. Especially, we conducted a Viewshed analysis for each potential wind farm site. The above maps and information could provide a basis for further scenario analysis at the municipal level. Furthermore, a more detailed on-site verification for the available sites could also be carried out based on this information.

In the meantime, in order to understand the current condition and issues in Kawamata town, a site visit (interview, site survey) was also conducted on July 5 and 6, 2014. The interview was carried out with the people from the Nuclear Emergency Response Department of Kawamata Government and the Yamakiya area neighborhood association. We visited “Rural Square” temporary house and decontamination working spaces in Yamakiya area. Two of the potential wind farm sites were observed during the visit as well.

4.4.6 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. Scenario analysis at the regional level provide input and output comparison of each scenario; preliminary study for scenario analysis at the municipal level can address more detailed information of each possible sites, provide integrated qualitative and quantitative information for local government and stakeholders.

4.5 Results

4.5.1 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 33. Population and primary energy consumption are illustrated for 2020 and 2030, see Figure 46-49.

Table 33. 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

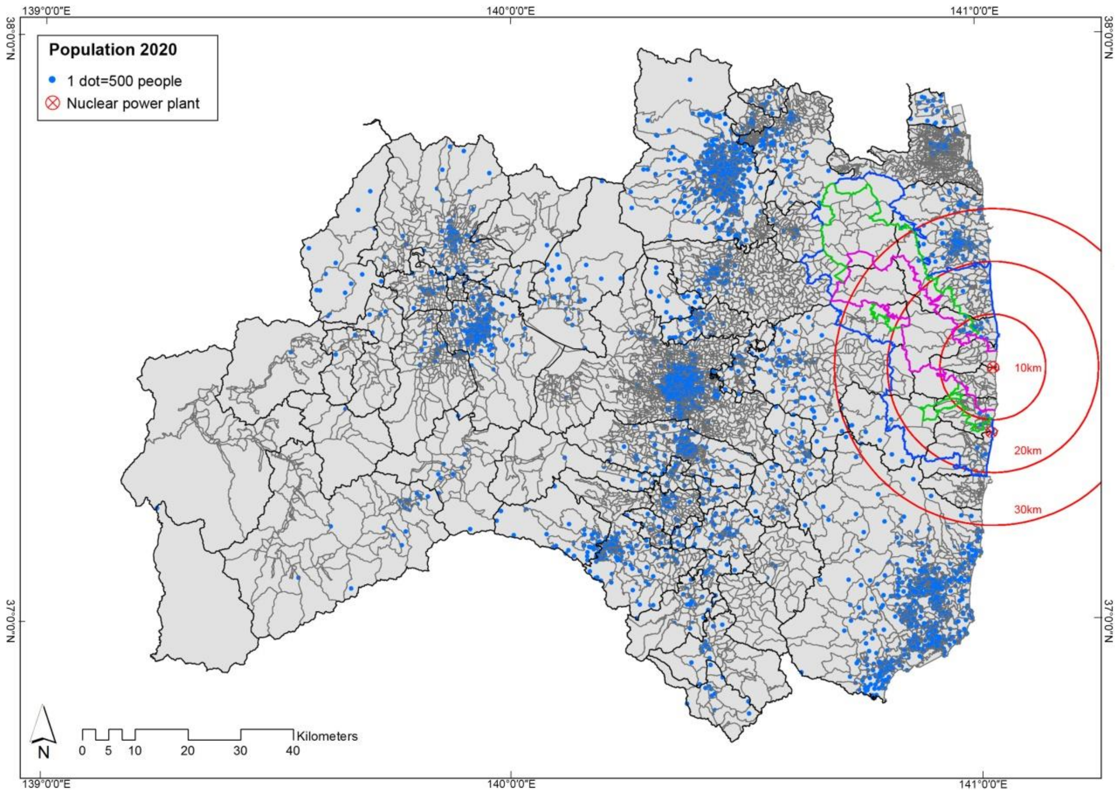


Figure 46. Fukushima's population in 2020. Colored lines shows evacuation directed areas. (Source: by author).

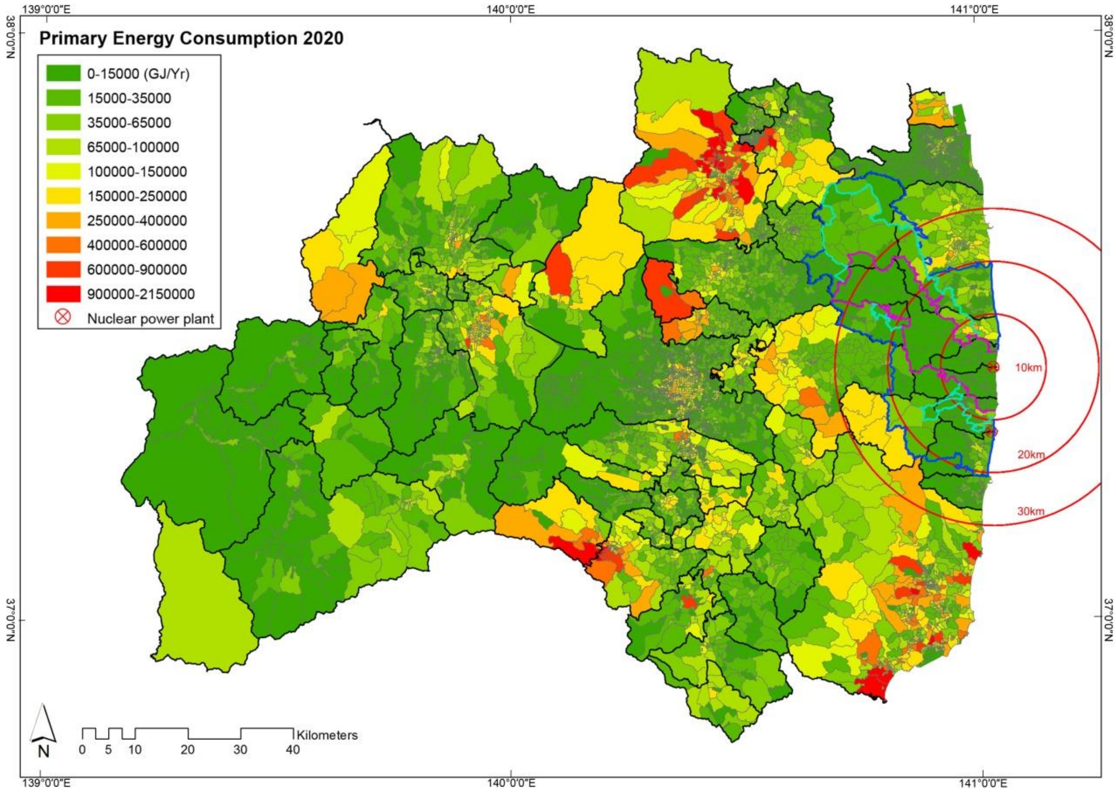


Figure 47. Fukushima's primary energy consumption in 2020. Colored lines shows evacuation directed areas. (Source: by author).

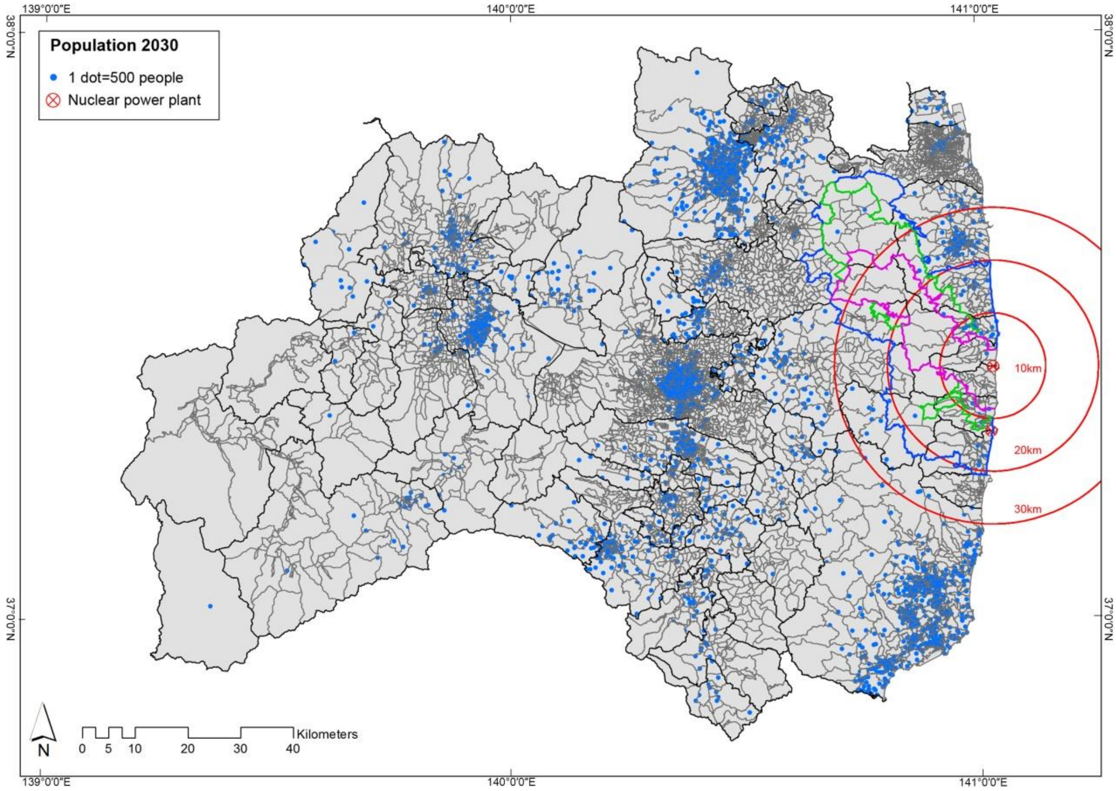


Figure 48. Fukushima’s population in 2030. Colored lines shows evacuation directed areas. (Source: by author).

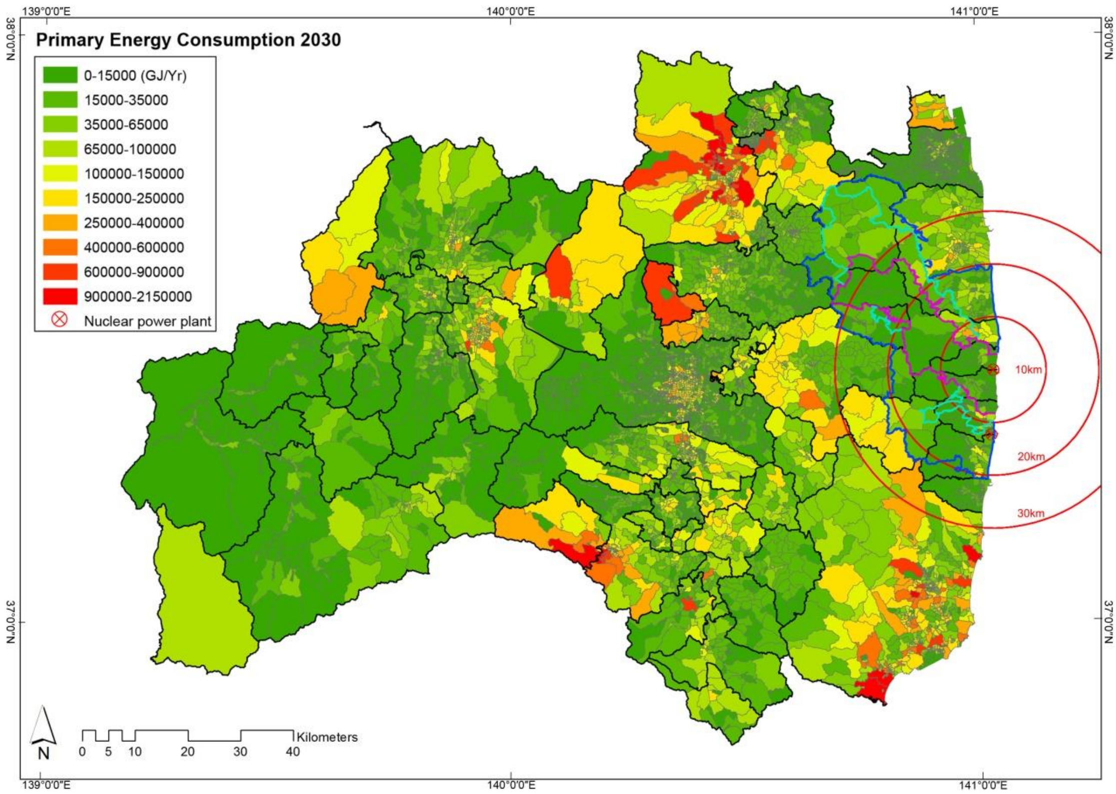


Figure 49. Fukushima’s primary energy consumption in 2030. Colored lines shows evacuation directed areas. (Source: by author).

4.5.2 Renewable Energy Potential: theoretical and available renewable energy potential

- Theoretical Renewable Energy Potential

The theoretical RE potential has been summarized in Table 34. 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 50-55.

Table 34. 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

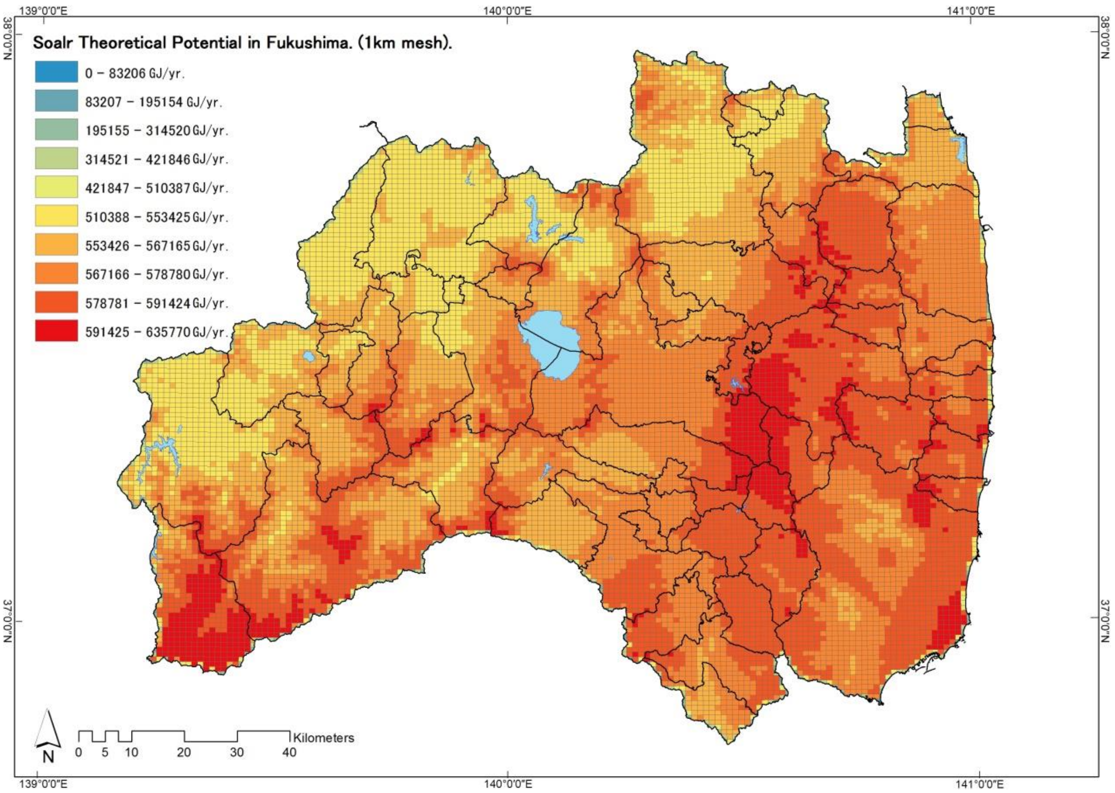


Figure 50. Solar theoretical potential. (Source: by author).

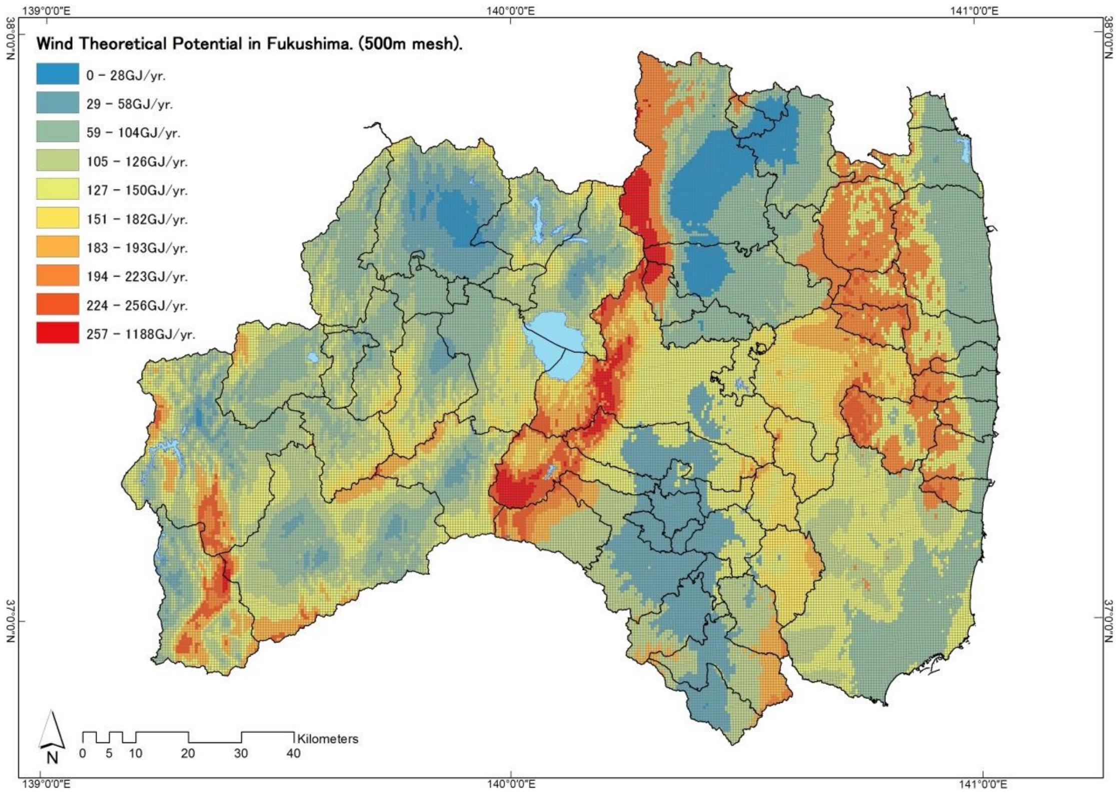


Figure 51. Wind theoretical potential. (Source: by author).

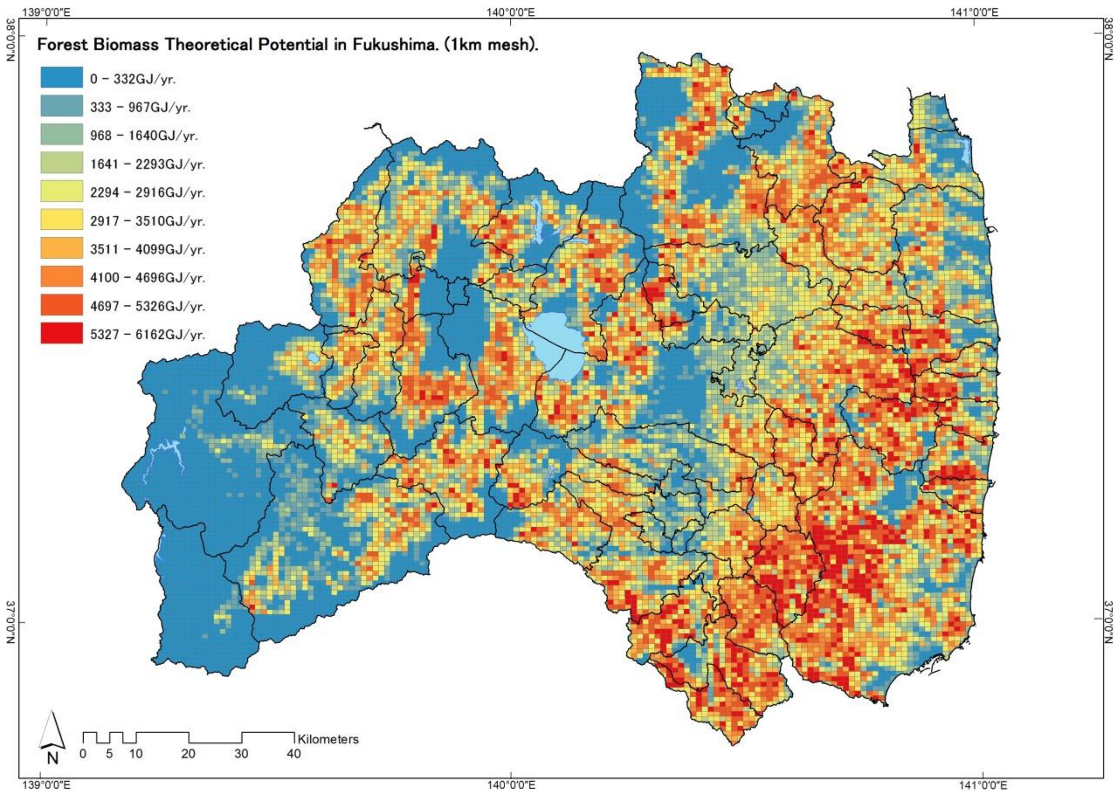


Figure 52. Forest biomass theoretical potential. (Source: by author).

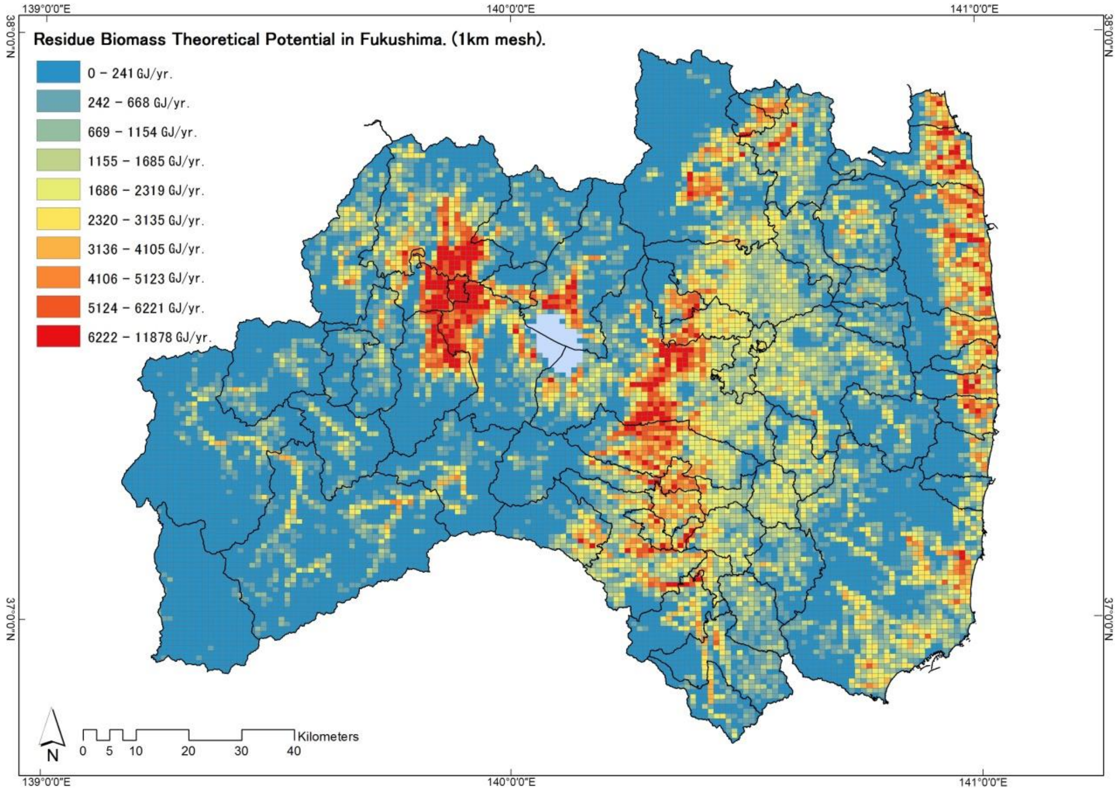


Figure 53. Residue biomass theoretical potential. (Source: by author).

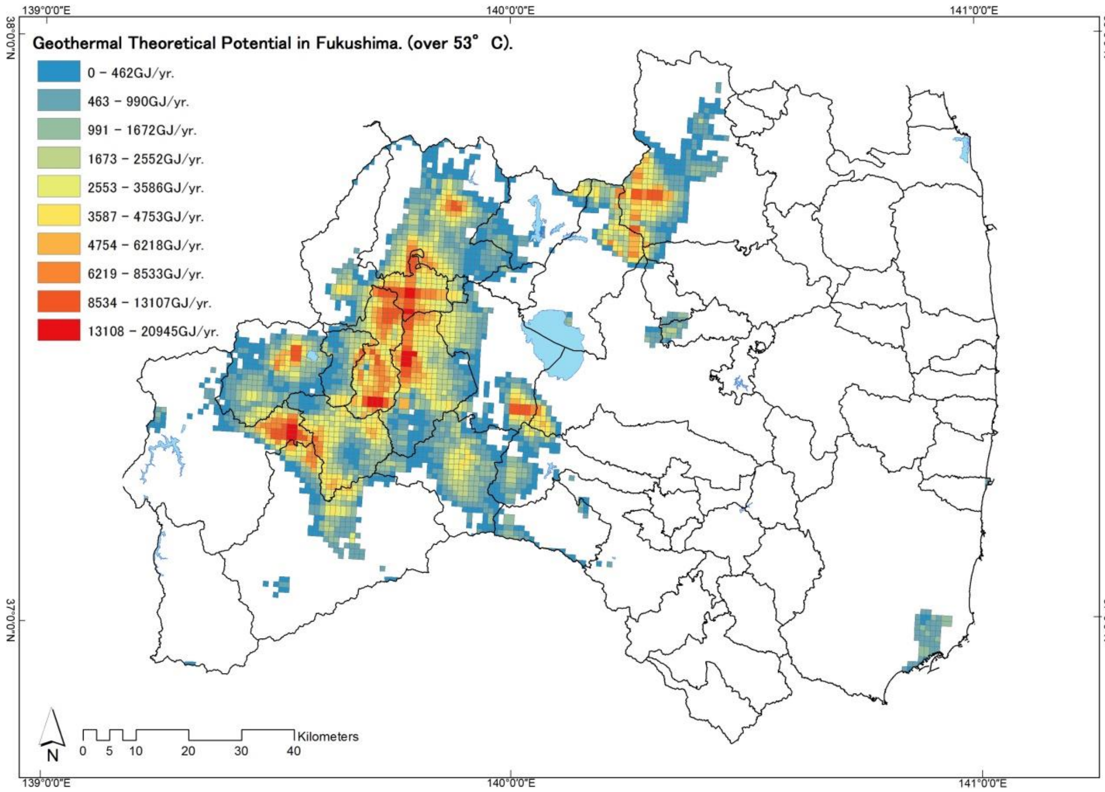


Figure 54. Geothermal theoretical potential. (Source: by author).

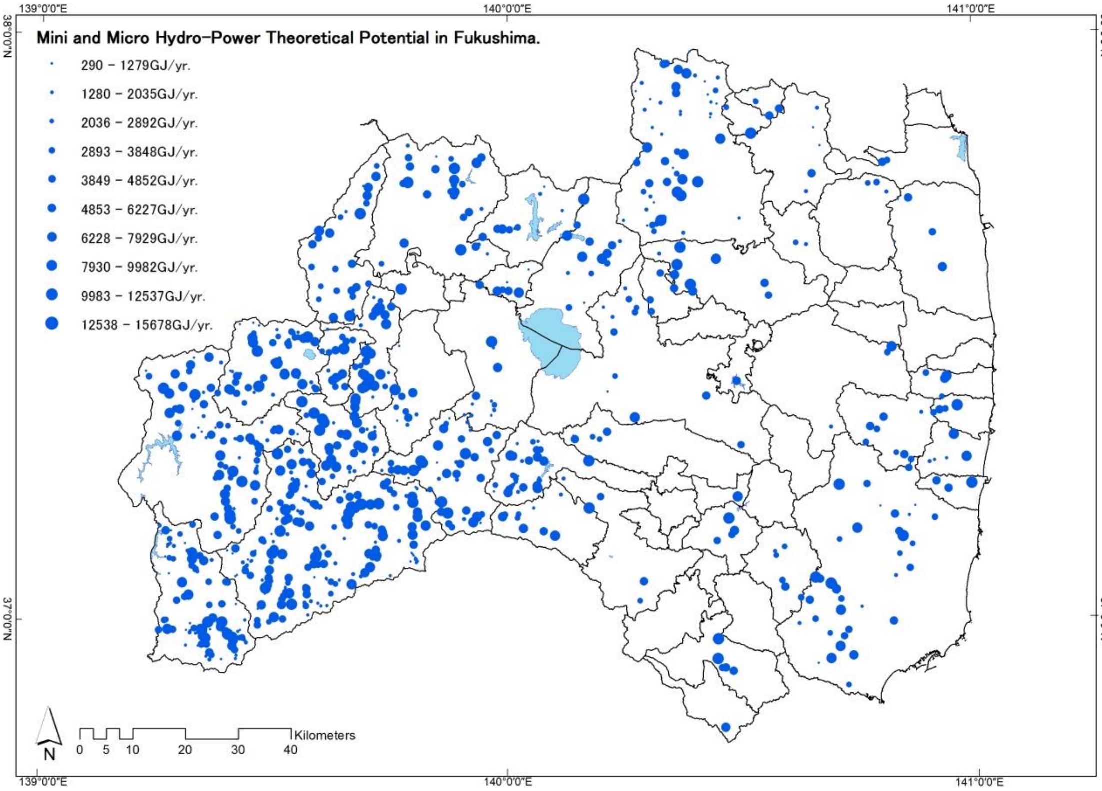


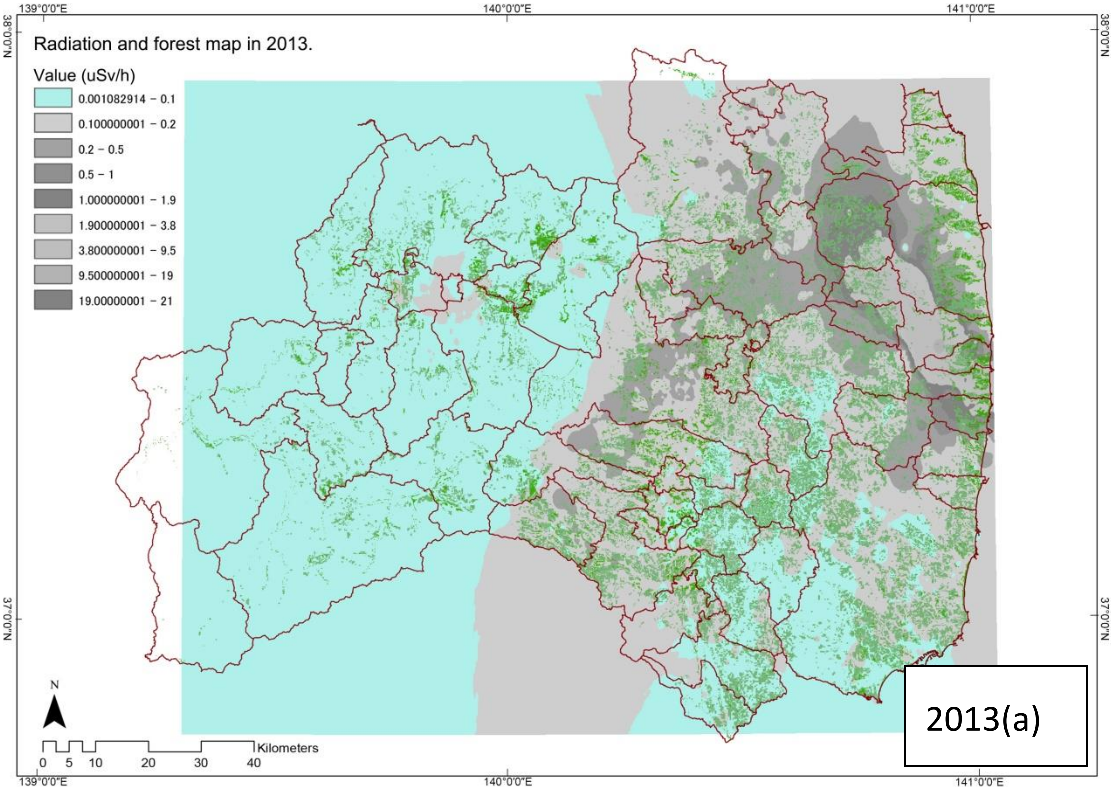
Figure 55. Hydro-power theoretical potential. (Source: by author).

- 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 56. After overlaying different criteria (expect for residue biomass), the available RE potential has been quantified, see Table 35. Furthermore, available sites with different potentials have been identified for each RES as well, see Figure 57-62.

Table 35. 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



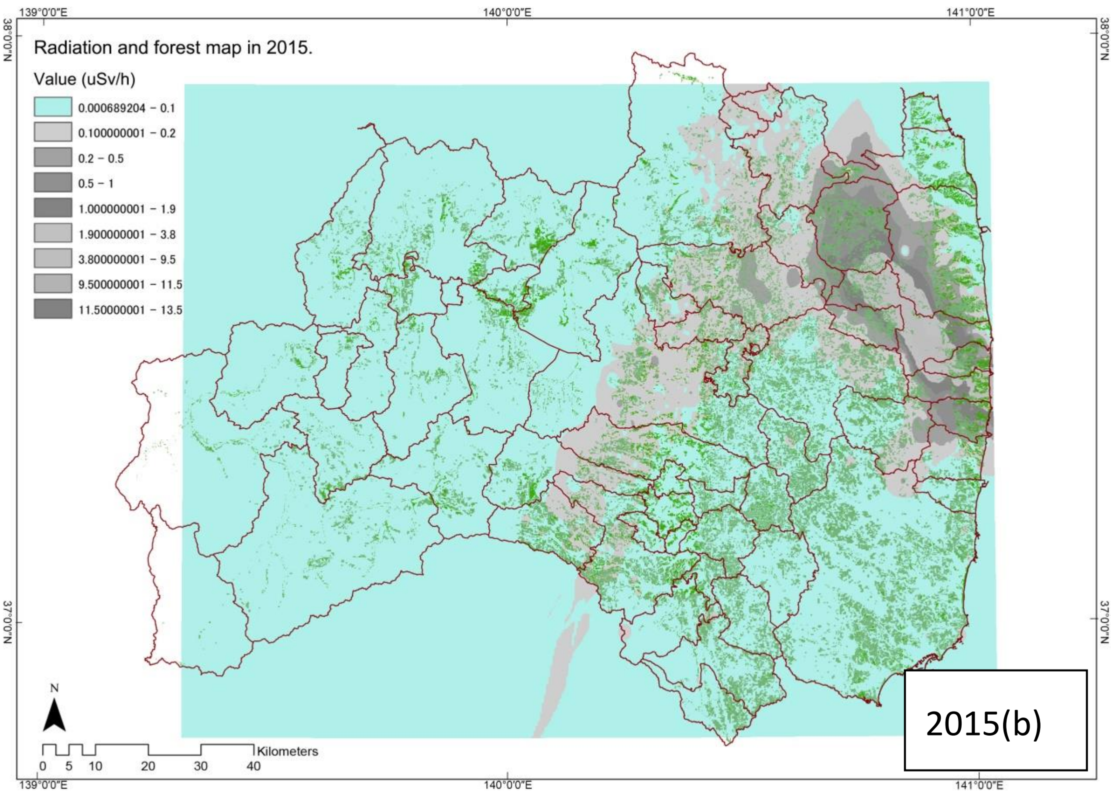
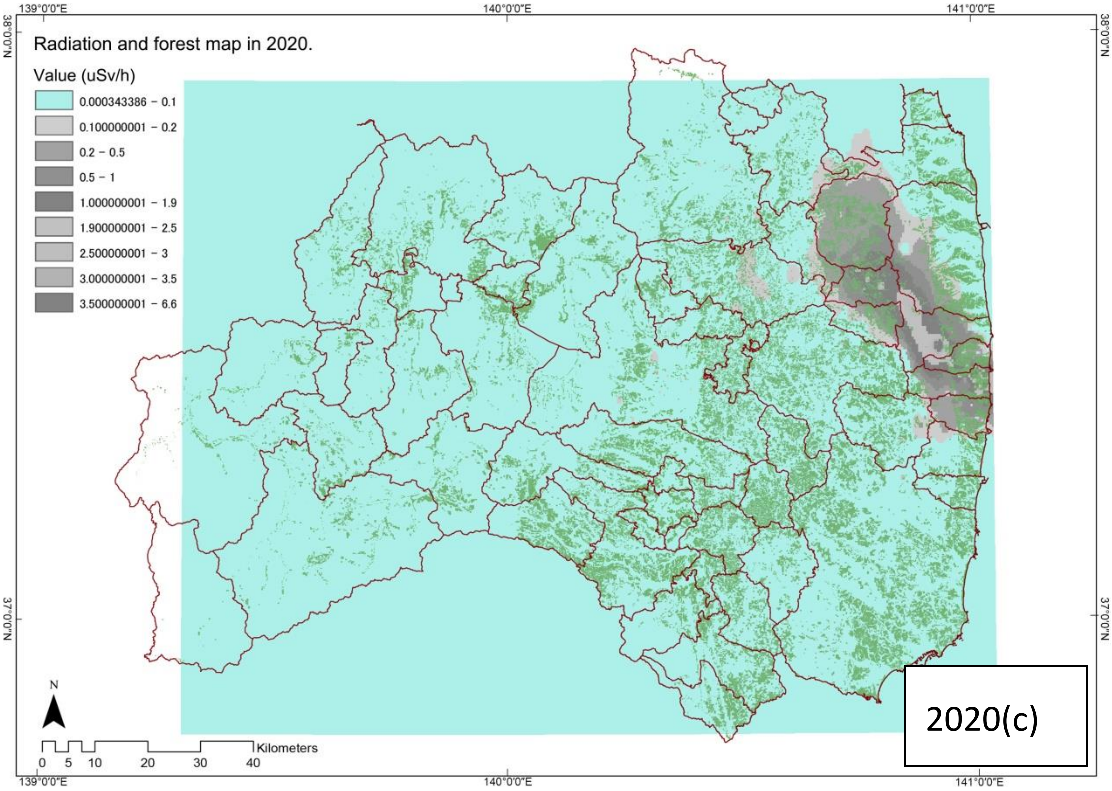


Figure 56. Radiation and forest map in 2013 (a); 2015 (b); 2020 (c); 2023 (d); 2028 (e); 2030 (f) in Fukushima. Aqua blue indicates areas under 0.1 μSv/h while grey indicates areas above 0.1 μSv/h. Green areas are the available forest areas before taking into account radiation conditions.



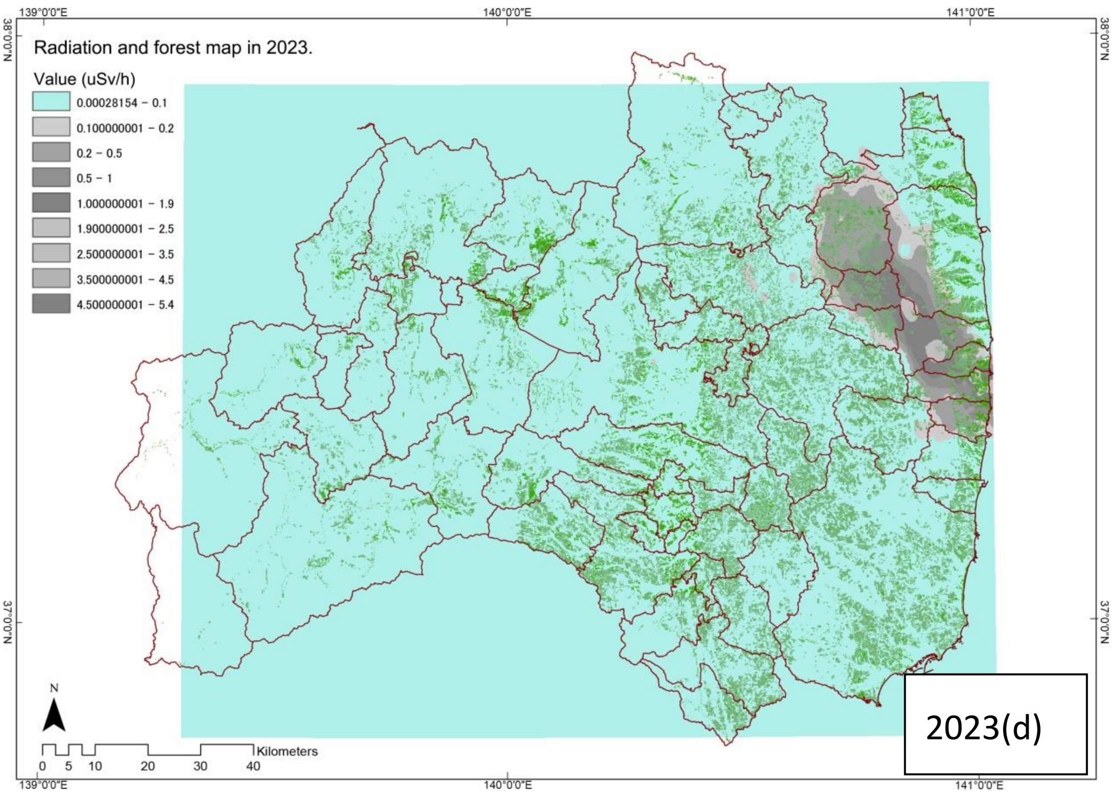
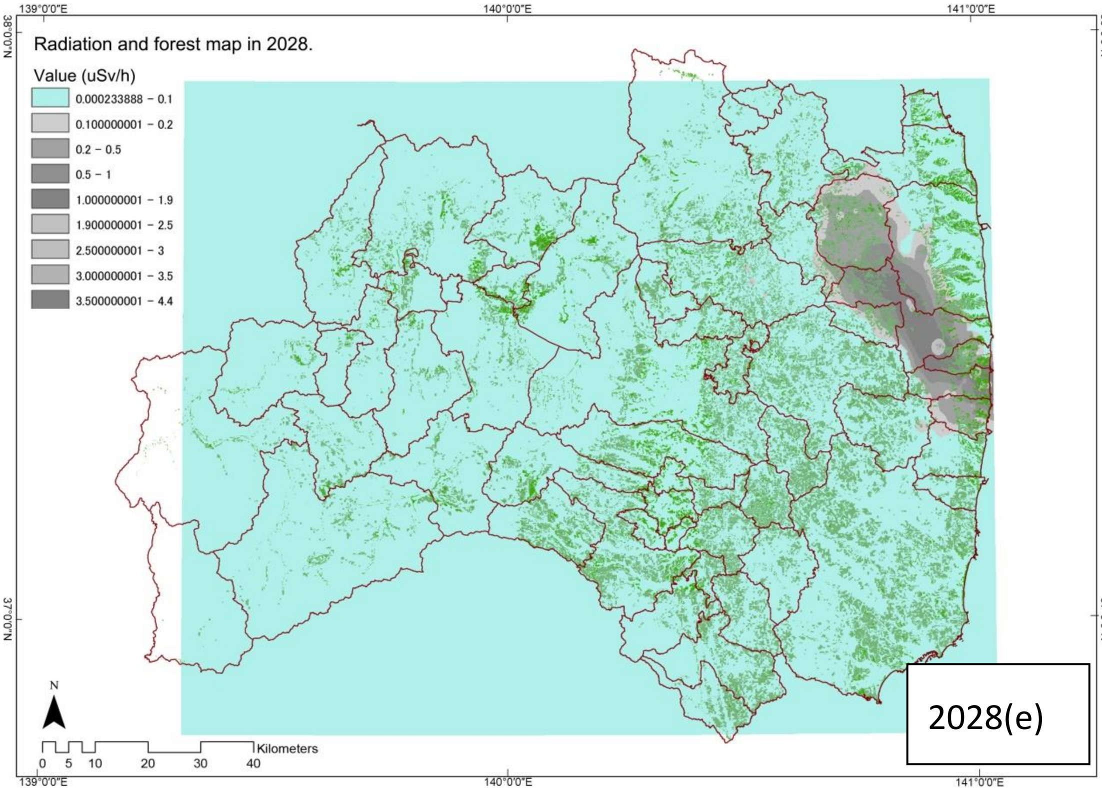


Figure 56. Radiation and forest map in 2013 (a); 2015 (b); 2020 (c); 2023 (d); 2028 (e); 2030 (f) in Fukushima. Aqua blue indicates areas under 0.1 μSv/h while grey indicates areas above 0.1 μSv/h. Green areas are the available forest areas before taking into account radiation conditions.



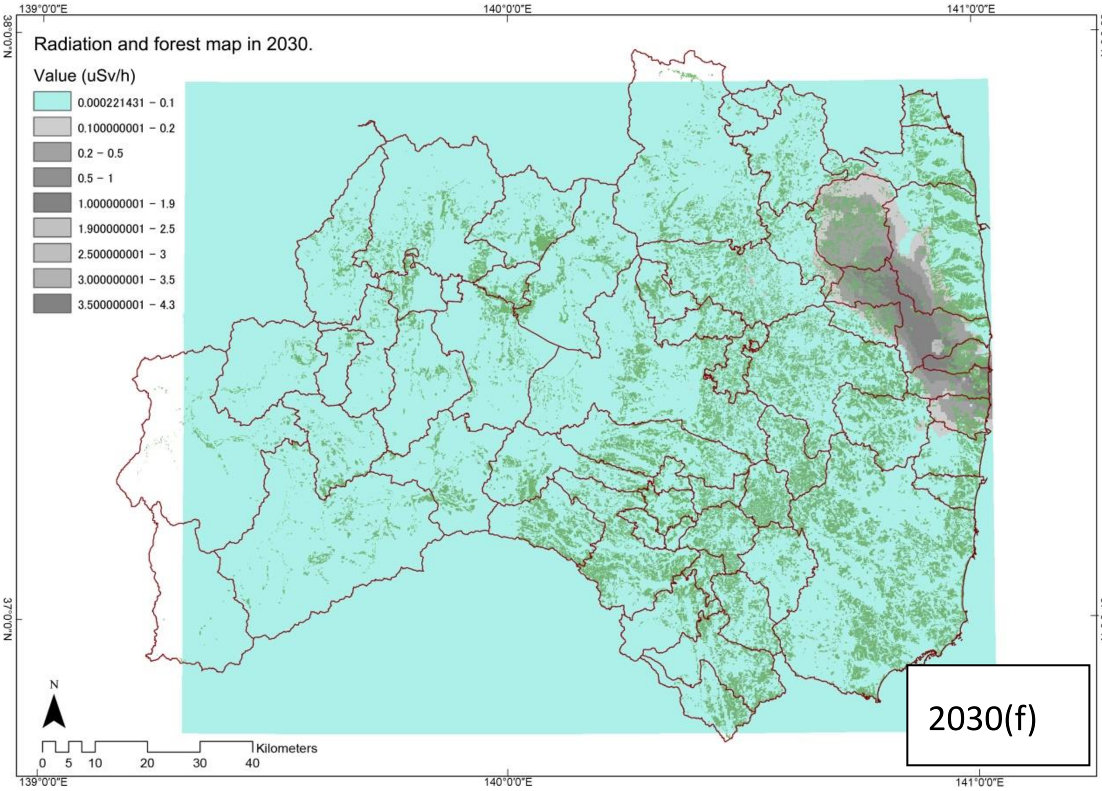


Figure 56. Radiation and forest map in 2013 (a); 2015 (b); 2020 (c); 2023 (d); 2028 (e); 2030 (f) in Fukushima. Aqua blue indicates areas under 0.1 μSv/h while grey indicates areas above 0.1 μSv/h. Green areas are the available forest areas before taking into account radiation conditions.

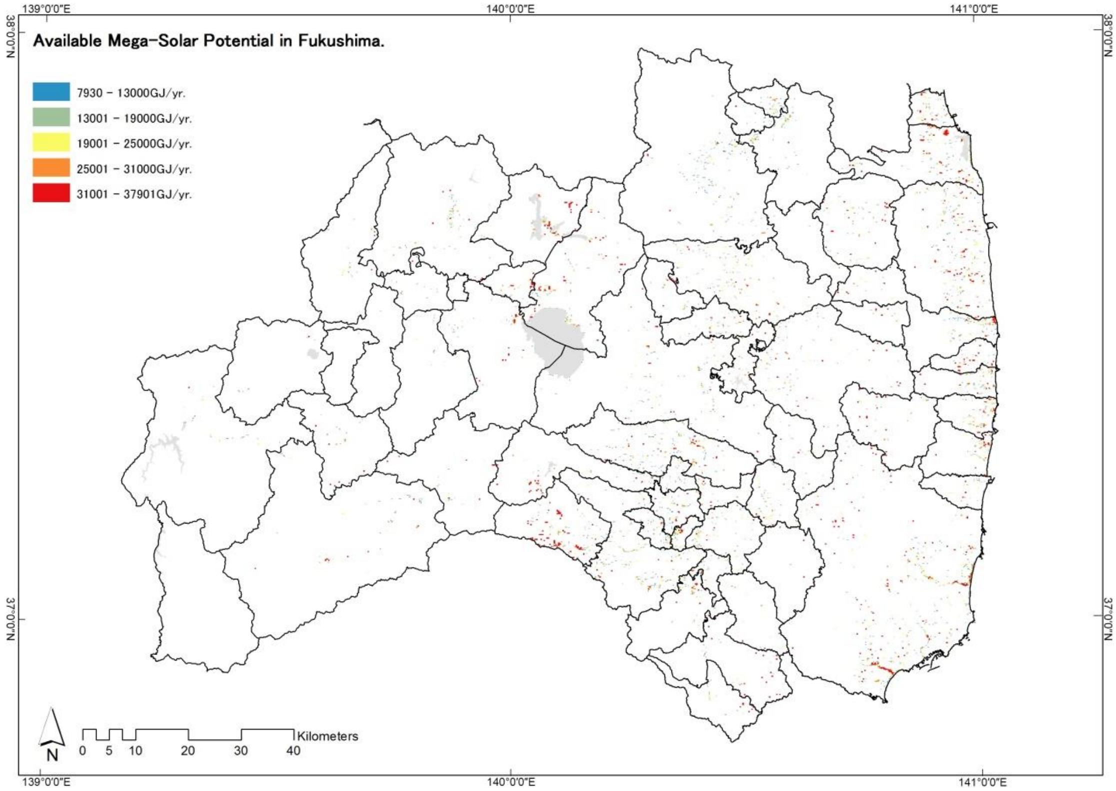


Figure 57. Available solar potential. (Source: by author).

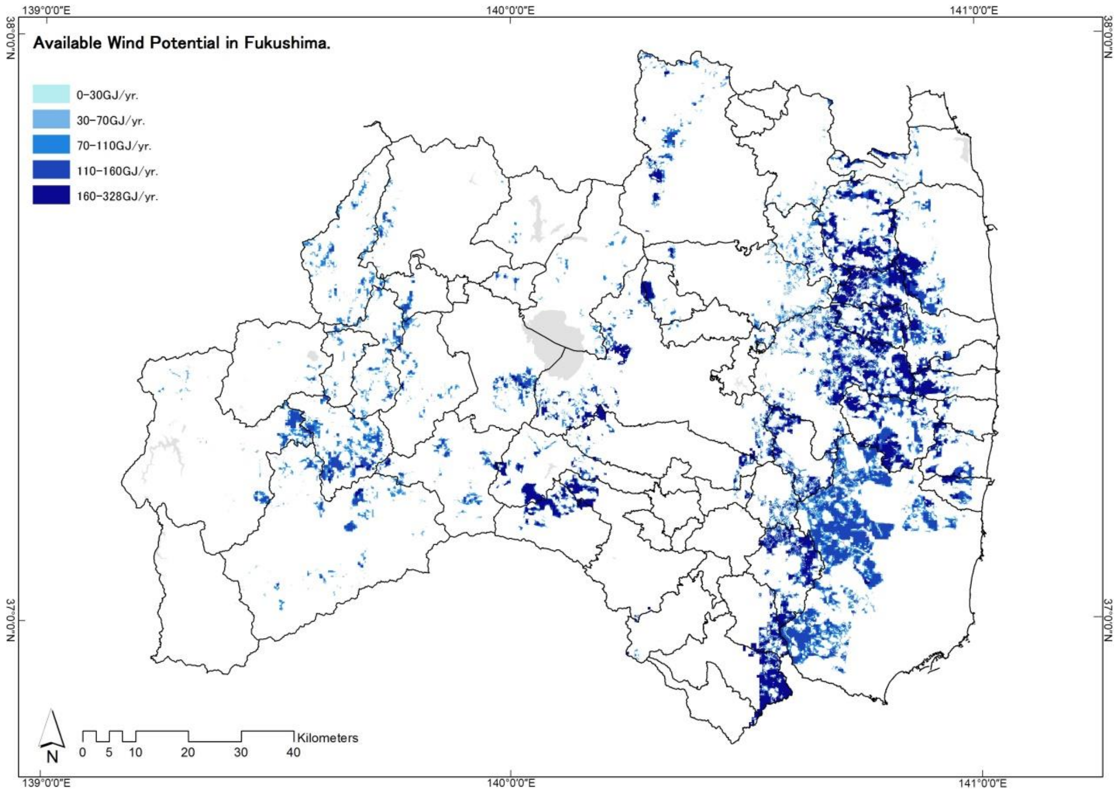


Figure 58. Available wind potential. (Source: by author).

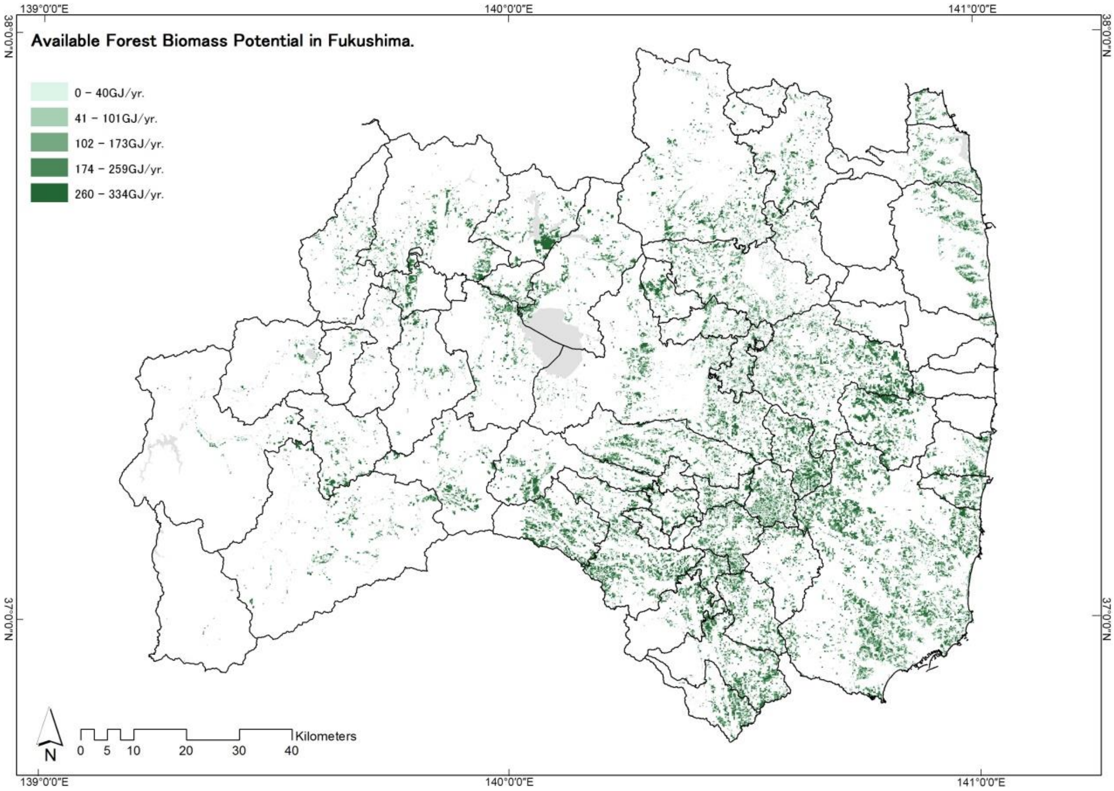


Figure 59. Available forest biomass potential. (Source: by author).

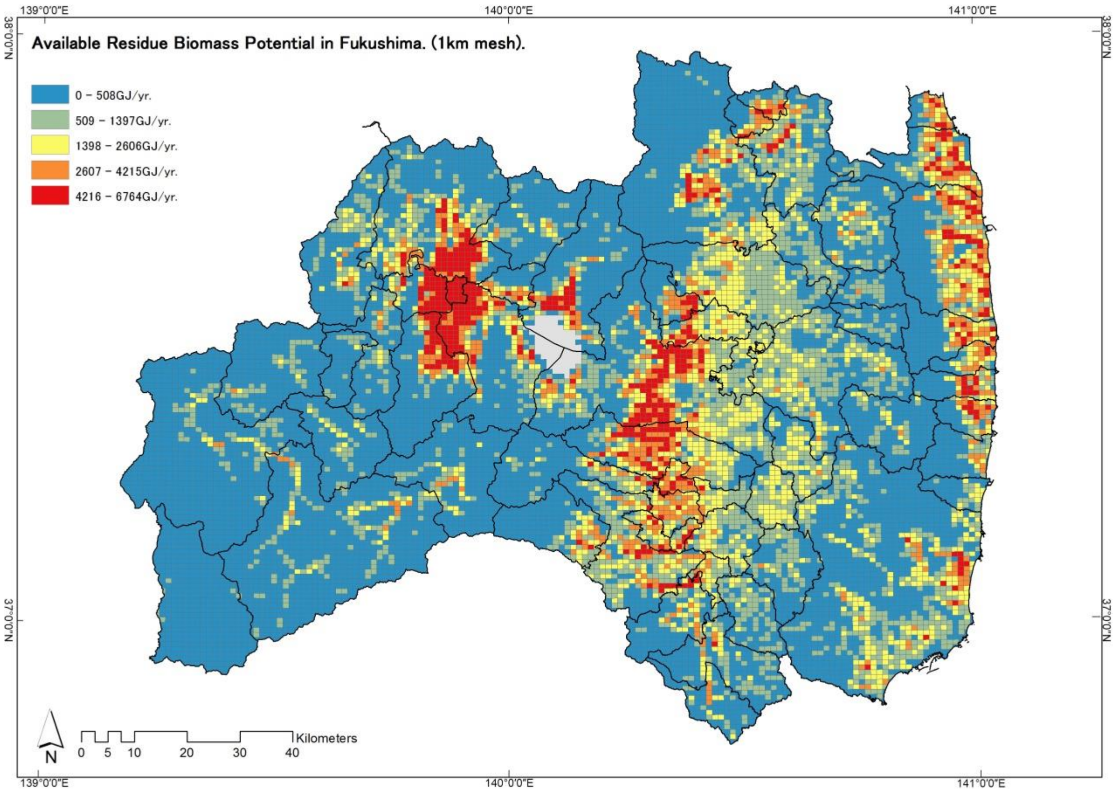


Figure 60. Available residue biomass potential. (Source: by author).

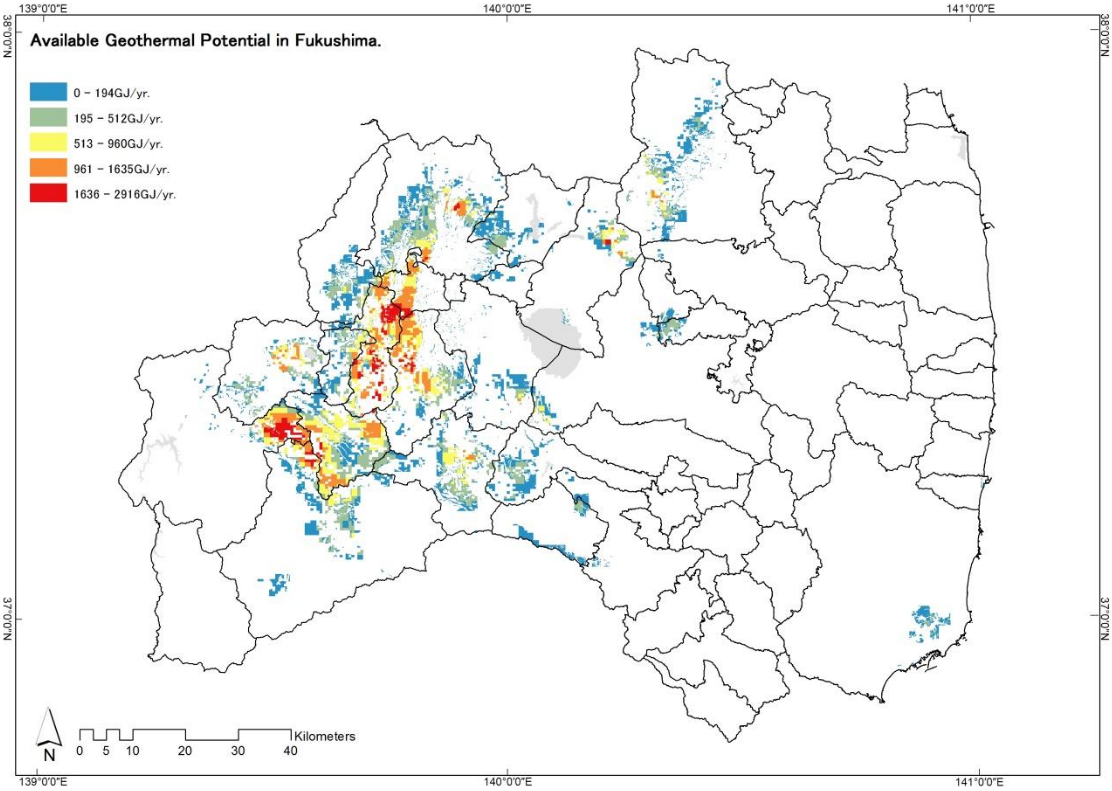


Figure 61. Available geothermal potential. (Source: by author).

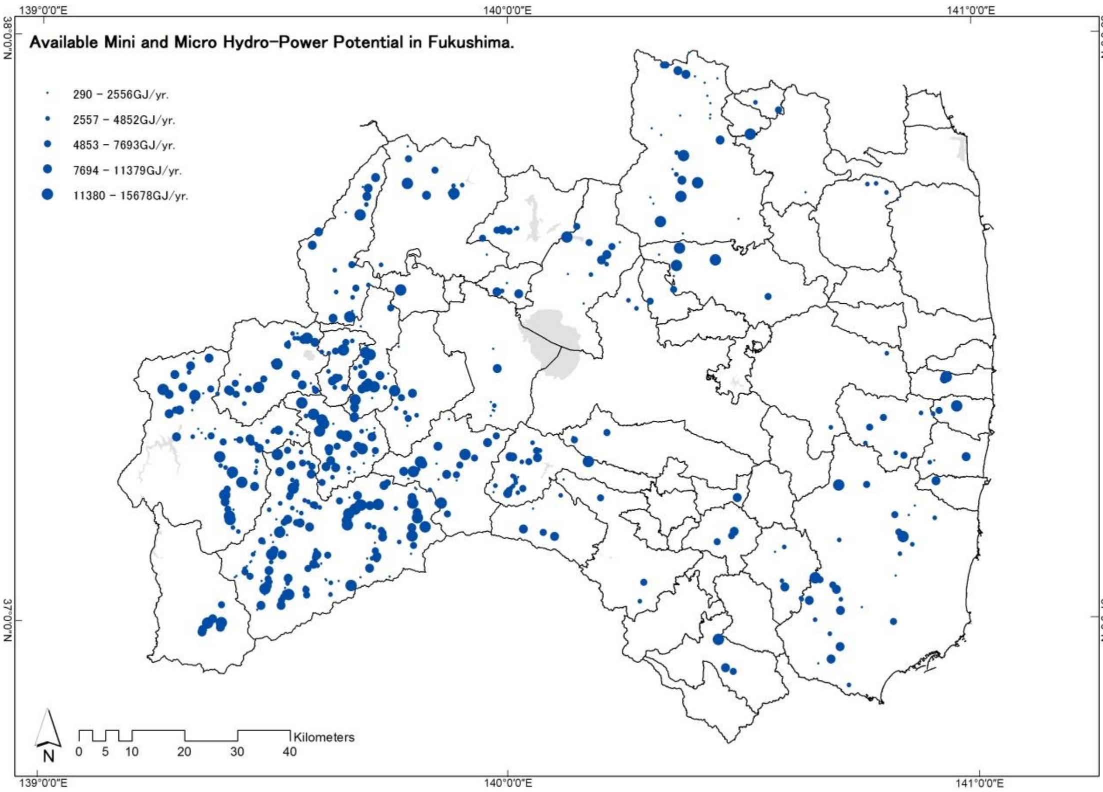


Figure 62. Available mini and micro hydro-power potential. (Source: by author).

4.5.3 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 63-64. 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 36.

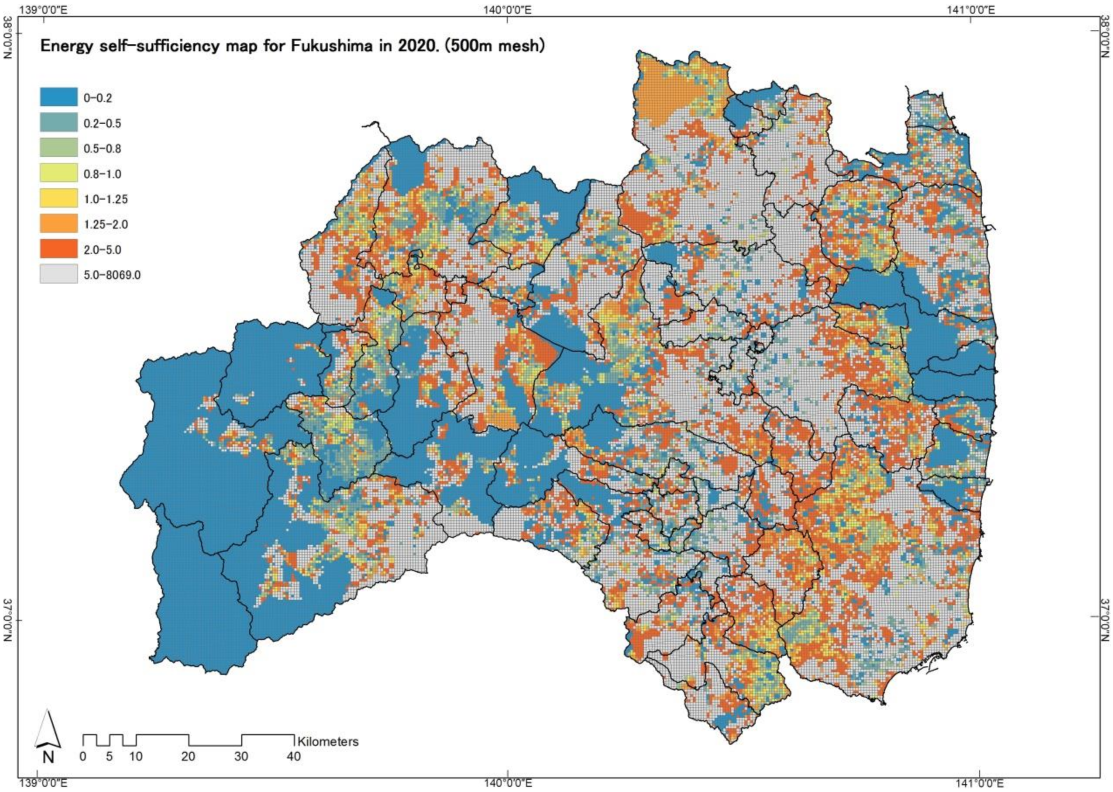


Figure 63. Energy self-sufficiency map for Fukushima in 2020. (Source: by author).

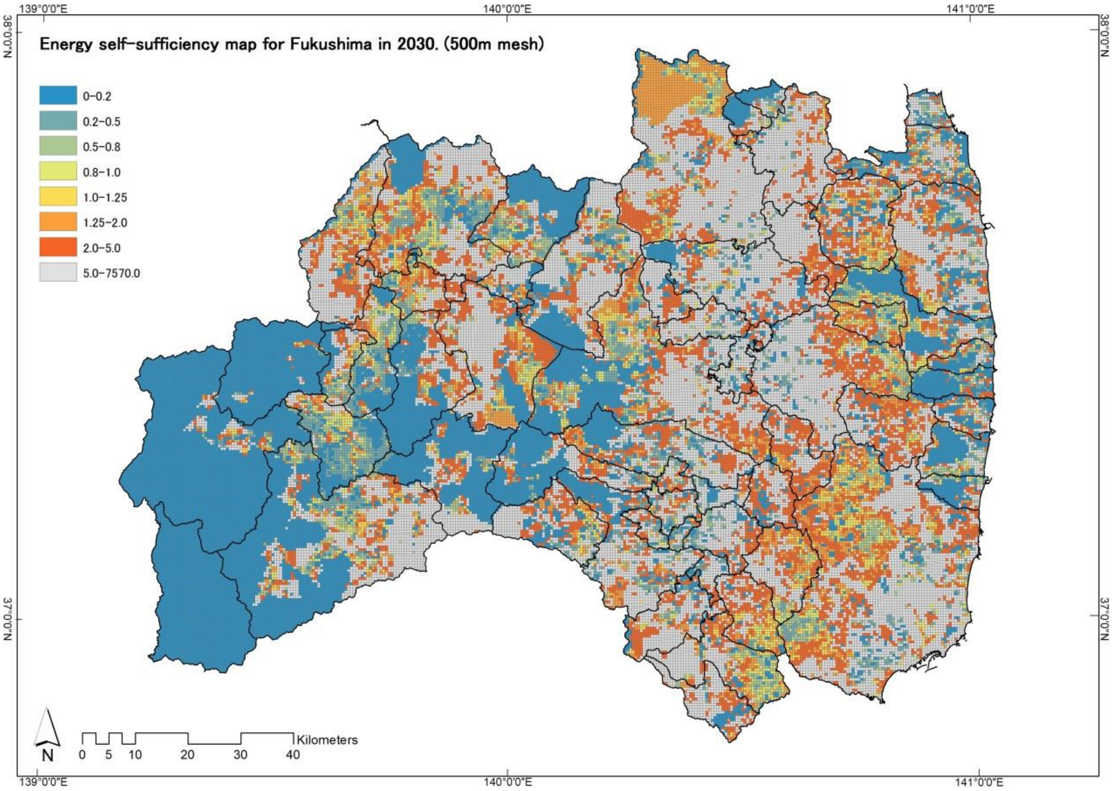


Figure 64. Energy self-sufficiency map for Fukushima in 2030. (Source: by author).

Table 36. 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%

4.5.4 Composite analysis map

Following the approach in Section 4.5.4, a composite map that shows available potential maps and other related information (urban areas, and buffers for heat transfer among others) can be generated using GIS. We used the available forest by 2020, to generate a sample map, see Figure 60. In Figure 60, 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.

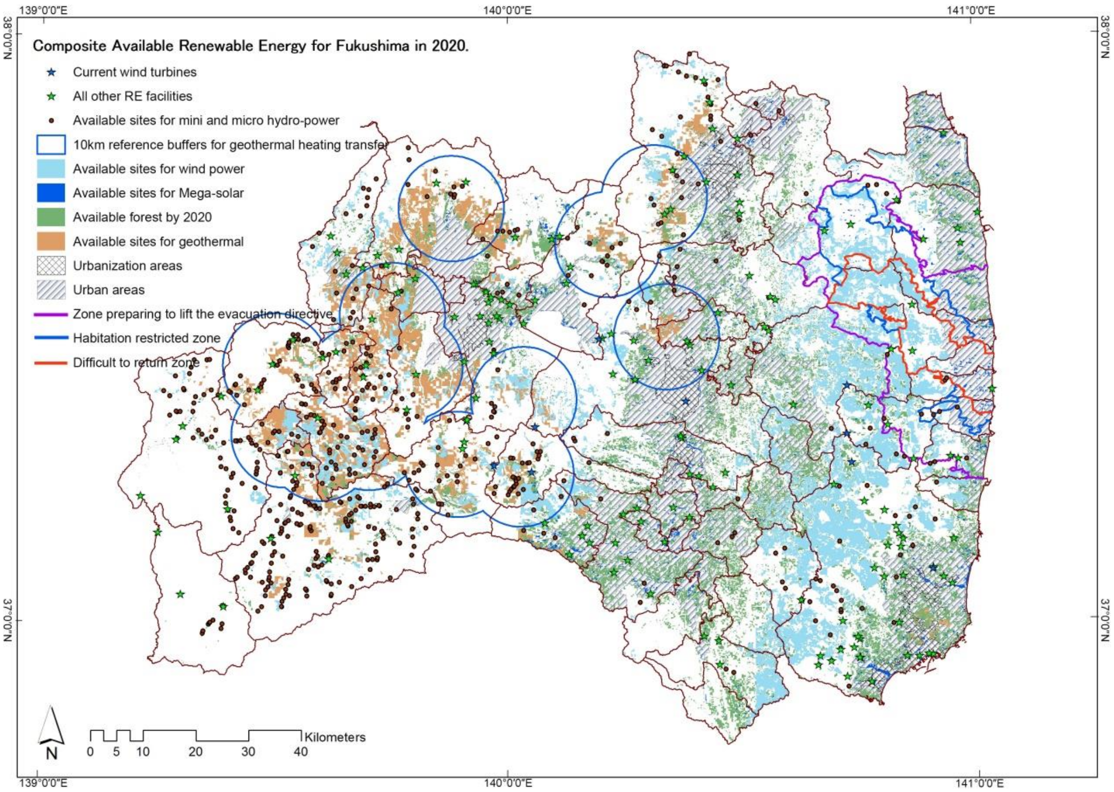


Figure 65. Composite available renewable energy potential map for Fukushima in 2020.

(Source: by author).

4.5.5 Scenario analysis

At the regional level, following the approach in Section 4.4.5, a zoning map that shows spatial distribution of RES in Fukushima was produced. See Figure 66. For Scenario 1-High objective, available sites with high RE potential were selected out, and combined with urban and urbanization areas in Fukushima. See Figure 67. The traced zoning map based on Figure 67 was generated as well, see Figure 68. Similarly, using the same approach, we generated the maps for Scenario 2-medium objective and Scenario 3-low objective. See Figure 69-70 and Figure 71-72.

Through comparing spatial distribution (zoning) of RES under the three different scenarios, it is discovered that the spatial distribution of RES between the three scenarios is similar. However, according to different levels of Fukushima's 2020 goal to achieve, the size of potential areas is different in the three scenarios. The higher goal to achieve, the bigger size of potential areas needs to be developed.

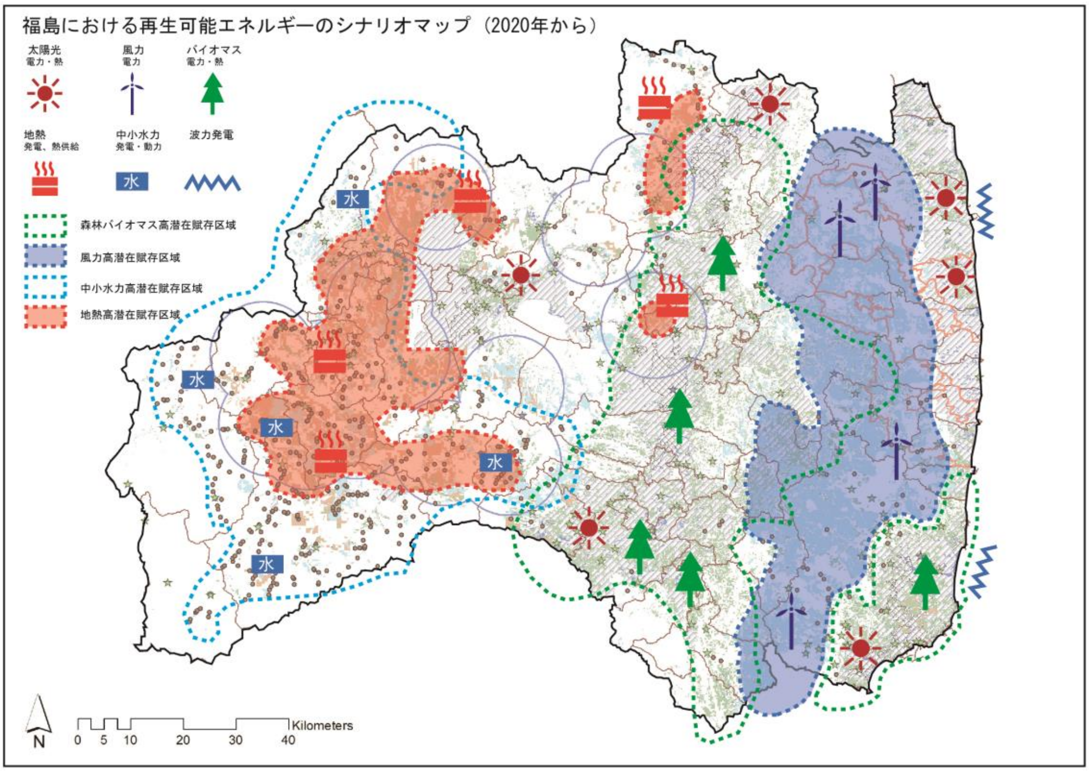


Figure 66. Zoning map-spatial distribution of different RES in Fukushima. (Source: by author).

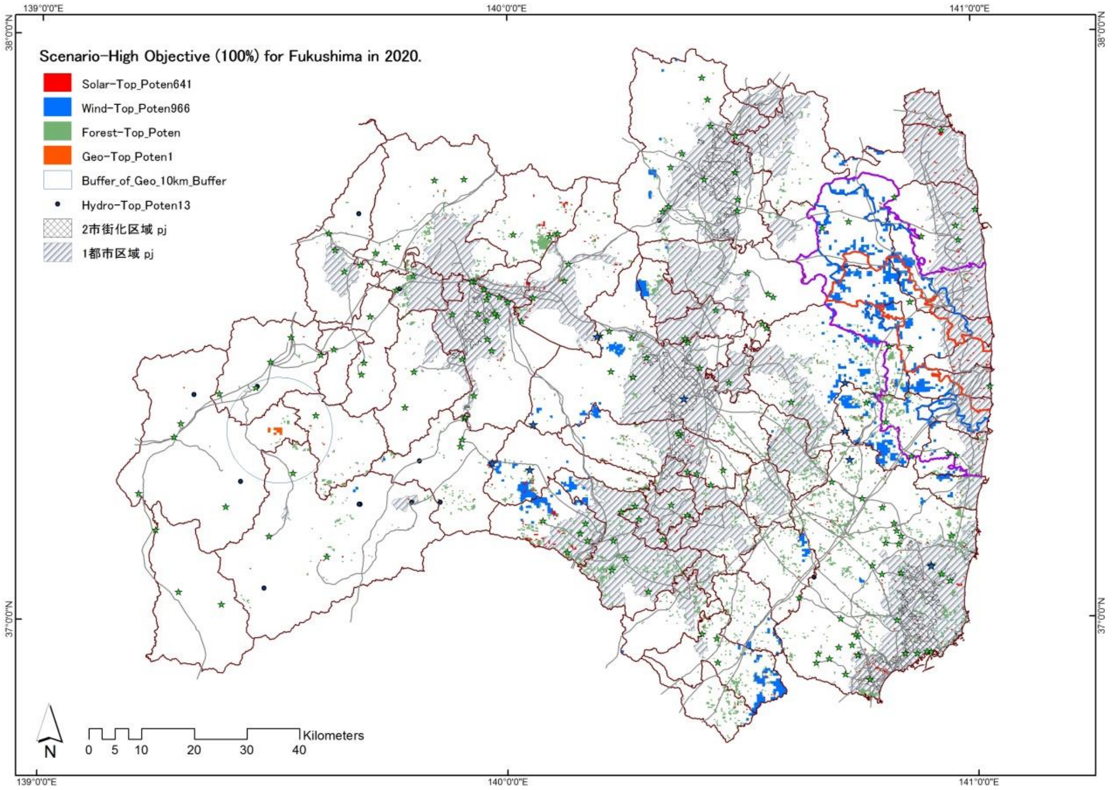


Figure 67. Original GIS map of Scenario 1-High objective. (Source: by author).

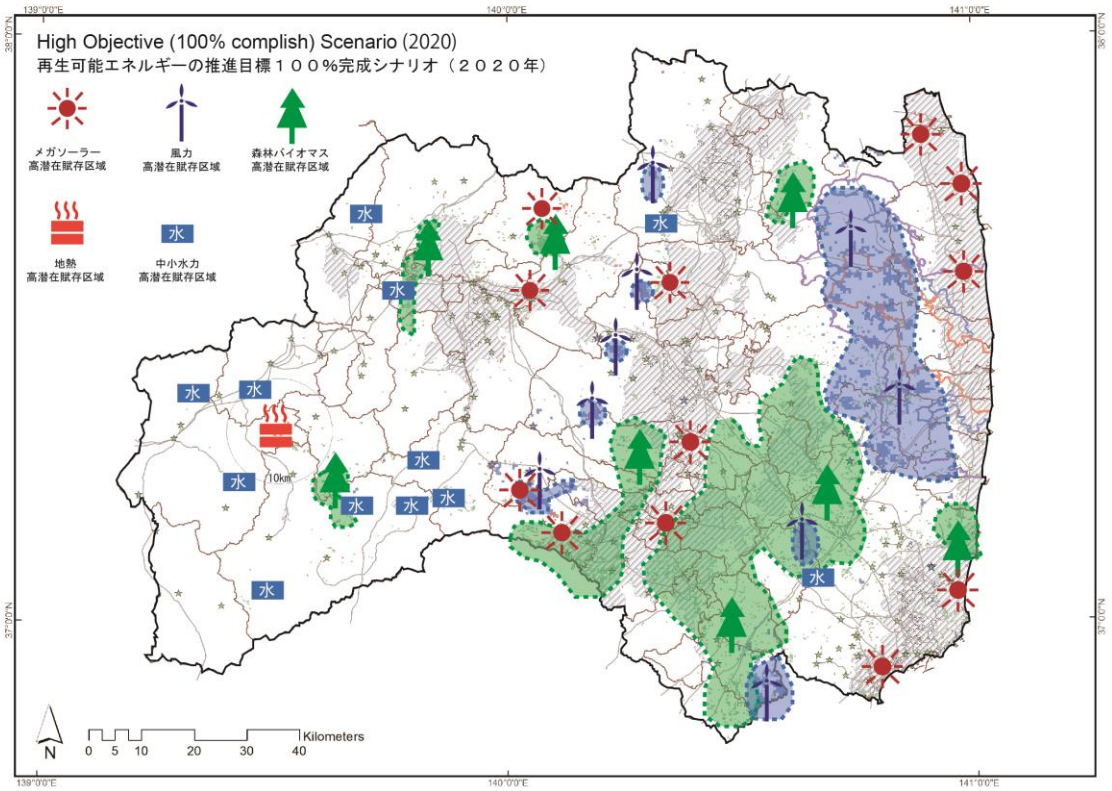


Figure 68. Zoning map of Scenario 1 that shown high potential sites and their spatial distribution.

(Source: by author).

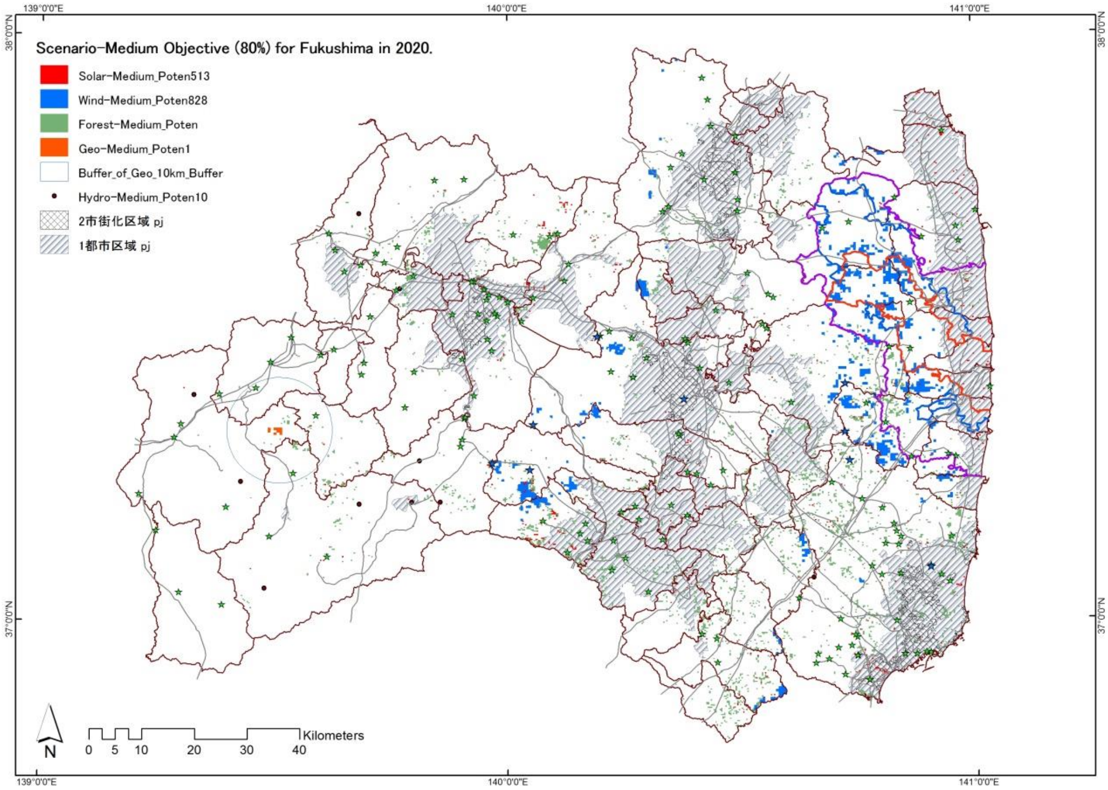


Figure 69. Original GIS map of Scenario 2-Medium objective. (Source: by author).

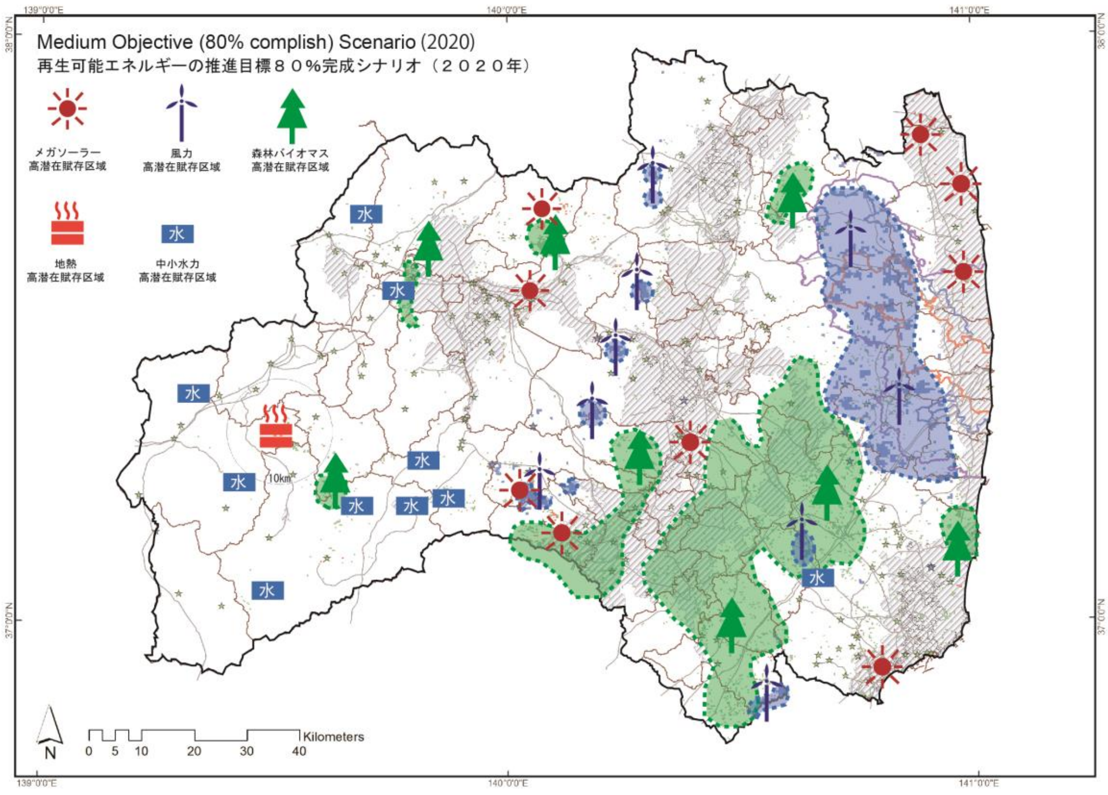


Figure 70. Zoning map of Scenario 2 that shown high potential sites and their spatial distribution.

(Source: by author).

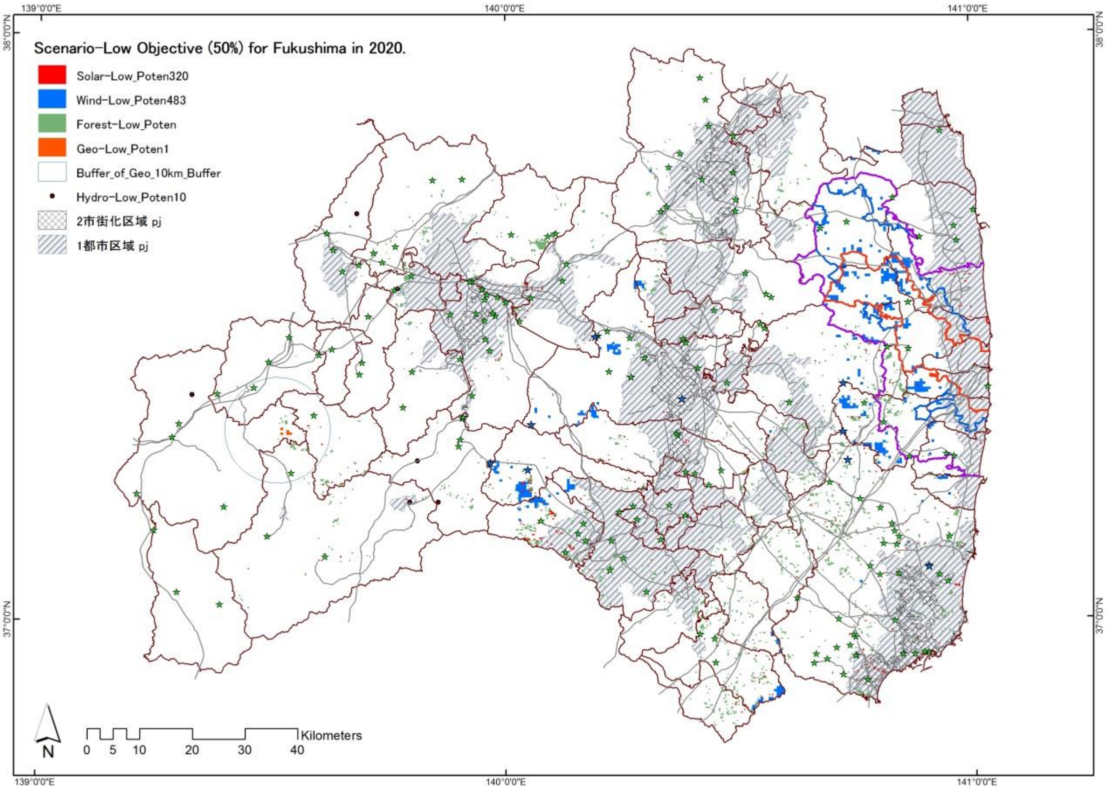


Figure 71. Original GIS map of Scenario 3-Low objective. (Source: by author).

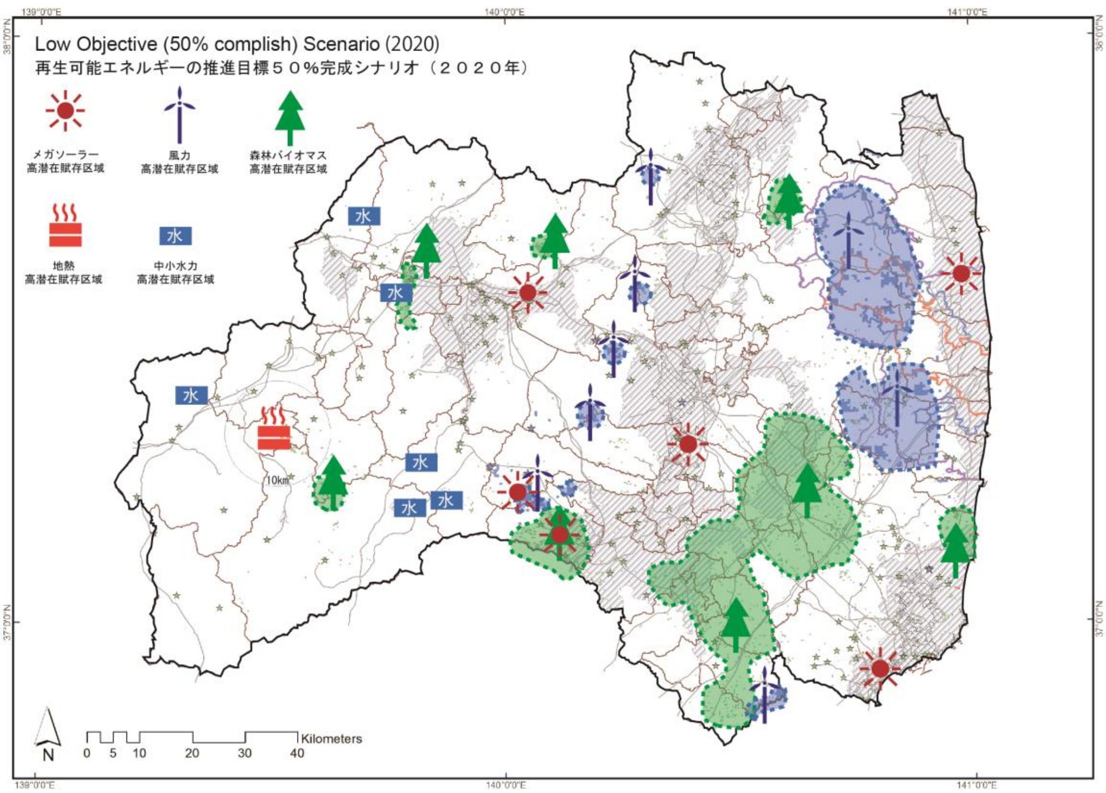


Figure 72. Zoning map of Scenario 3 that shown high potential sites and their spatial distribution.

(Source: by author).

Similarly, the factor comparison results (Table 37) show that, according to different levels of Fukushima's 2020 goal, to achieve the input, such as construction costs and the output, such as electricity production and CO_2 reduction per year, is different in the three scenarios. The higher the goal, the more input investment is needed; consequently, more output will be obtained in the future.

Table 37. Different results of scenario comparison factors.

	Scenario-1 High 100%	Scenario-2 Medium 80%	Scenario-3 Low 50%
Construction fee (JPY)	1,014,516 M	793,910 M	507,230 M
Electricity production in a year (kWh) (Electricity selling income-JPY)	4,949,154,720 (120,190 M)	3,883,658,400 (94,350 M)	2,474,437,200 (60,010 M)
Supply number of houses(family)	89,984	70,612	44,989
CO_2 reduction amount(t)	2,870,509.7t	2,252,521.9t	1,385,684.8t

At the municipal level, a preliminary study for scenario analysis in Kawamata town was conducted. In GIS, we zoomed in to Kawamata town level and generated its RES potential map based on a regional composite map. We then combined it with the Kawamata downtown land use map, national forest boundary, protected forest boundary, evacuation boundary, and new public housing. See Figure 73. It was discovered that there are three main RES within Kawamata town. They are solar energy, wind power, and biomass resources (forest and agriculture residue). The code numbers for potential sites of each RES are shown in Figure 74-76.

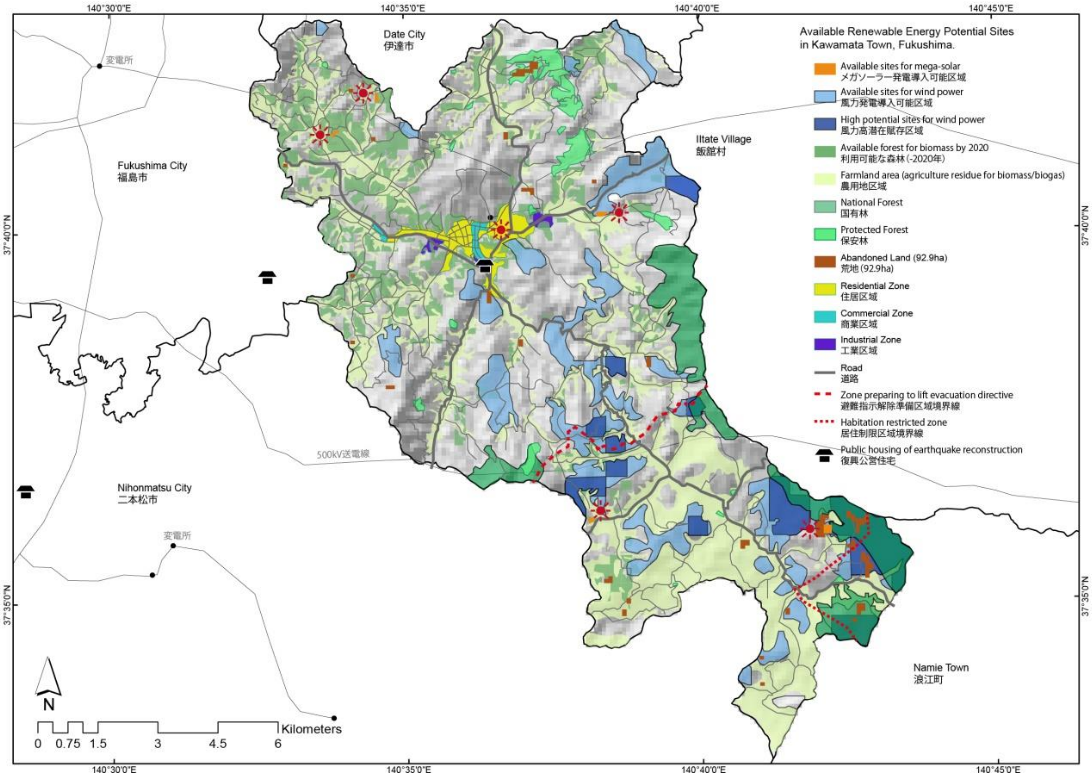


Figure 73. RES potential map in Kawamata town. (Source: by author).

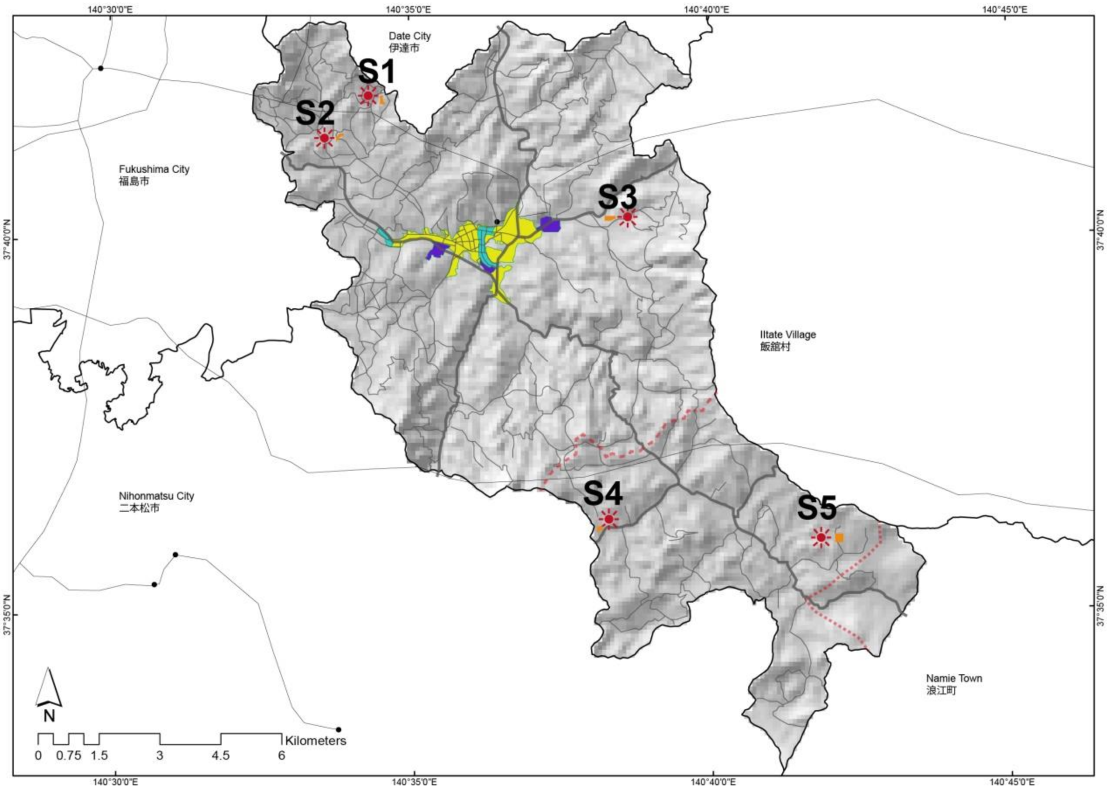


Figure 74. Code number for potential mega-solar sites. (Source: by author).

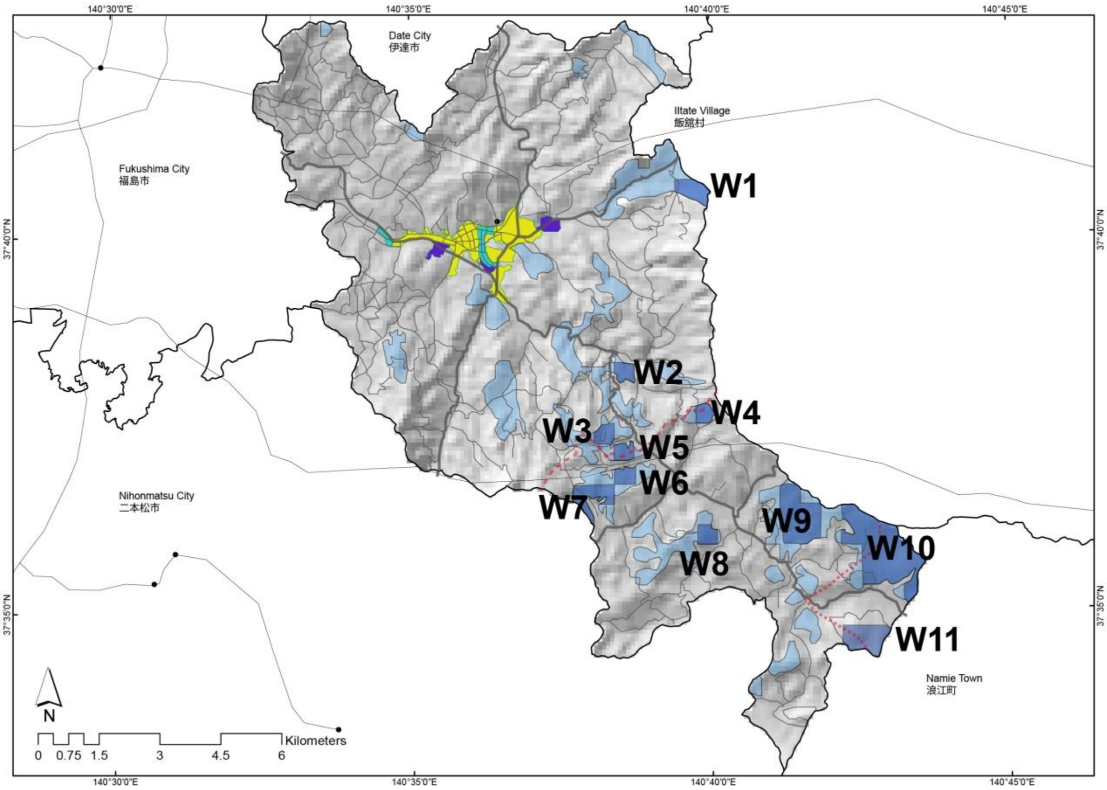


Figure 75. Code number for potential wind farm sites. (Source: by author).

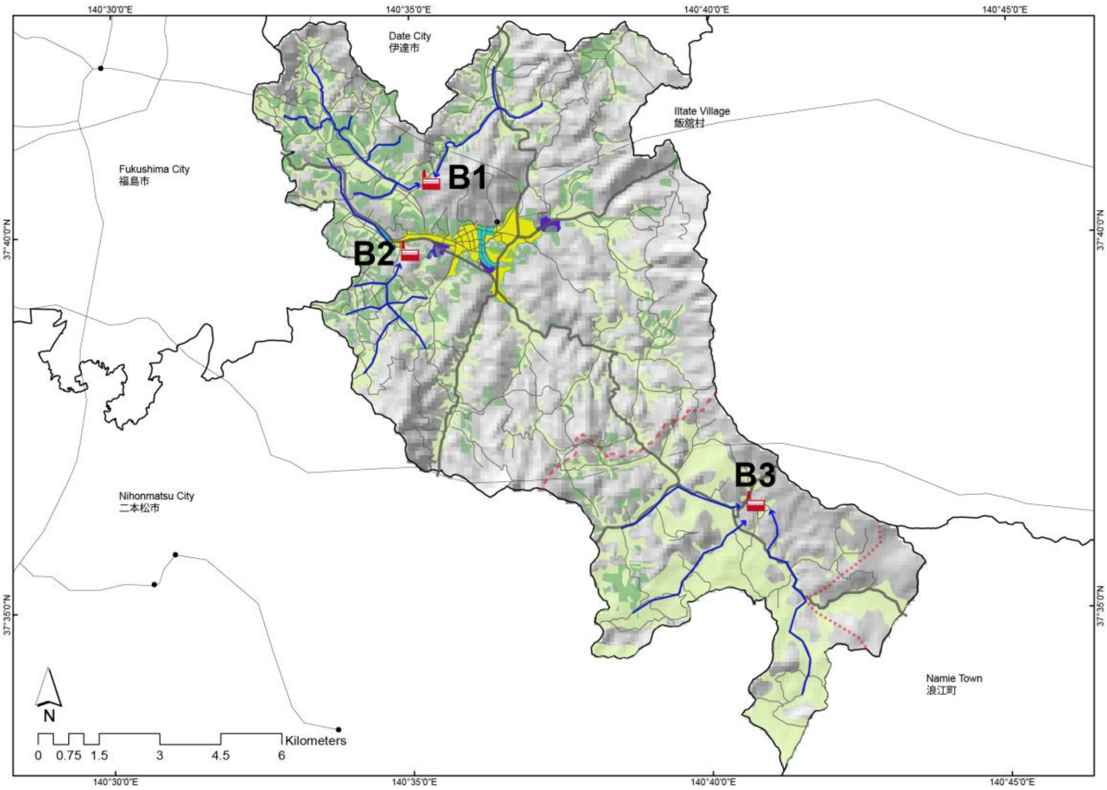


Figure 76. Code number for potential biomass plant sites. (Source: by author).

The summarized detail information for each coded site is shown in Table 38-40. Viewshed analysis for eleven potential wind farm sites was conducted as well. Viewshed analysis can provide visual impact simulation for wind farms at the municipal level. Thus, the GIS-based simulation results can support decision making for wind farm site selection in Kawamata town. See Figure 77-88.

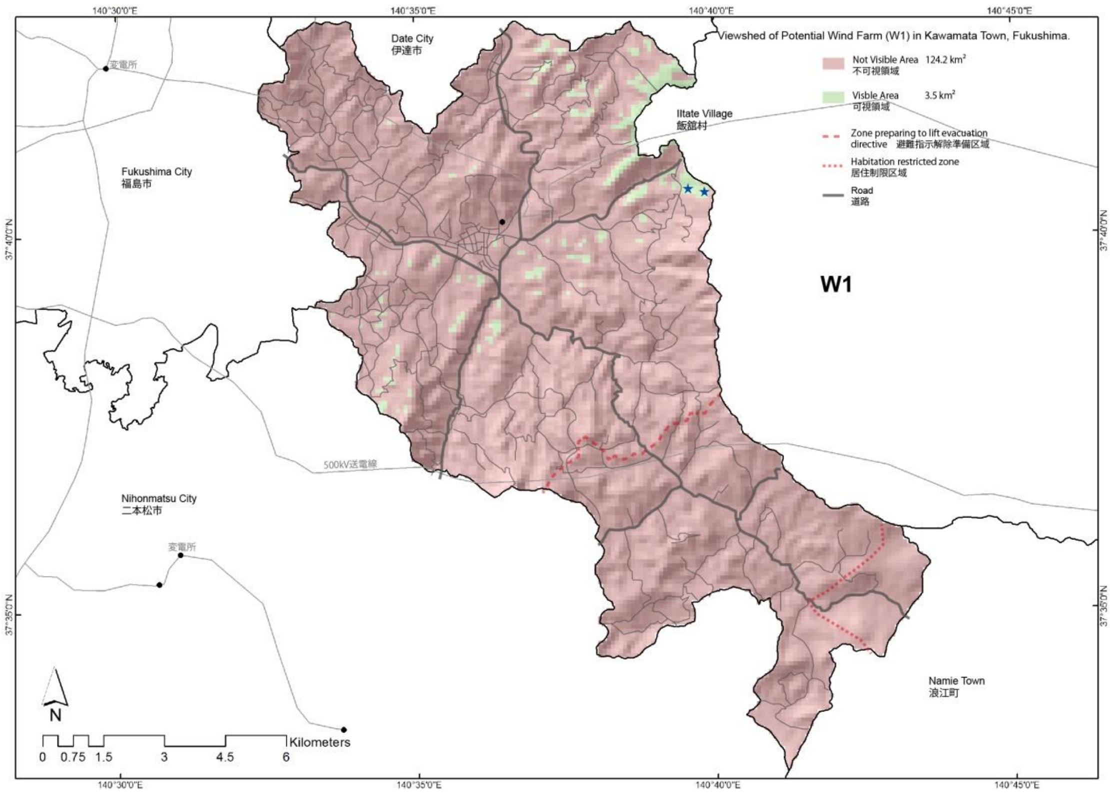


Figure 77. Viewshed maps of wind farm potential sites W1. (Source: by author).

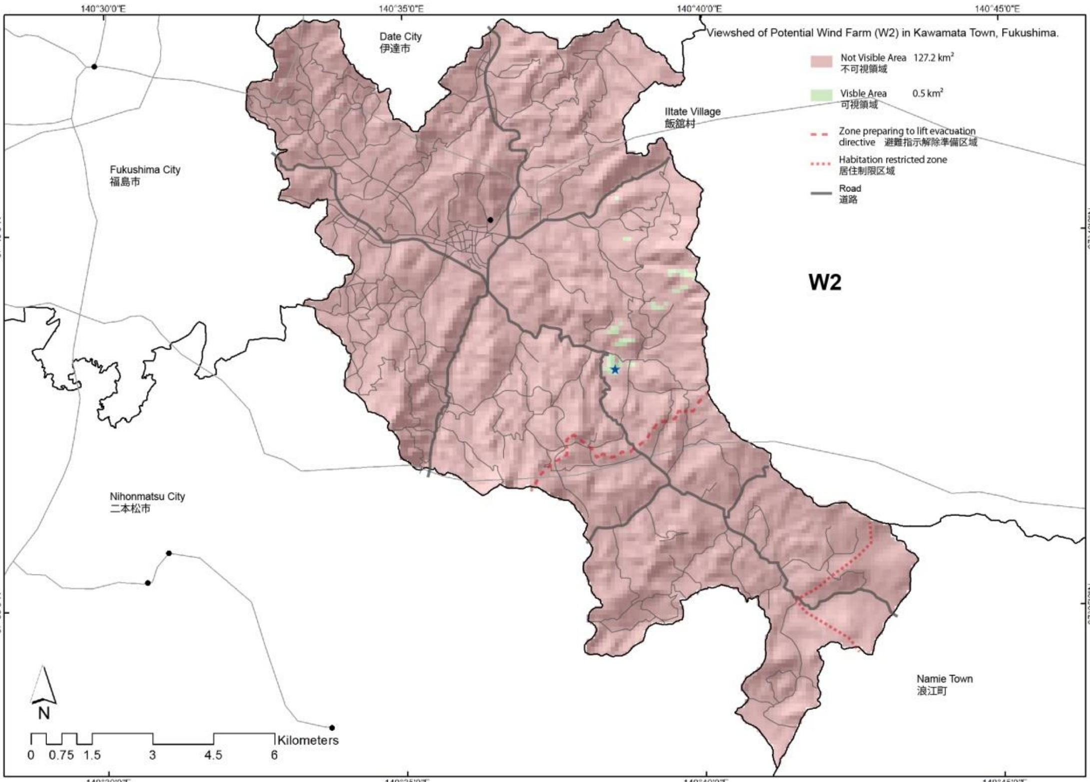


Figure 78. Viewshed maps of wind farm potential sites W2. (Source: by author).

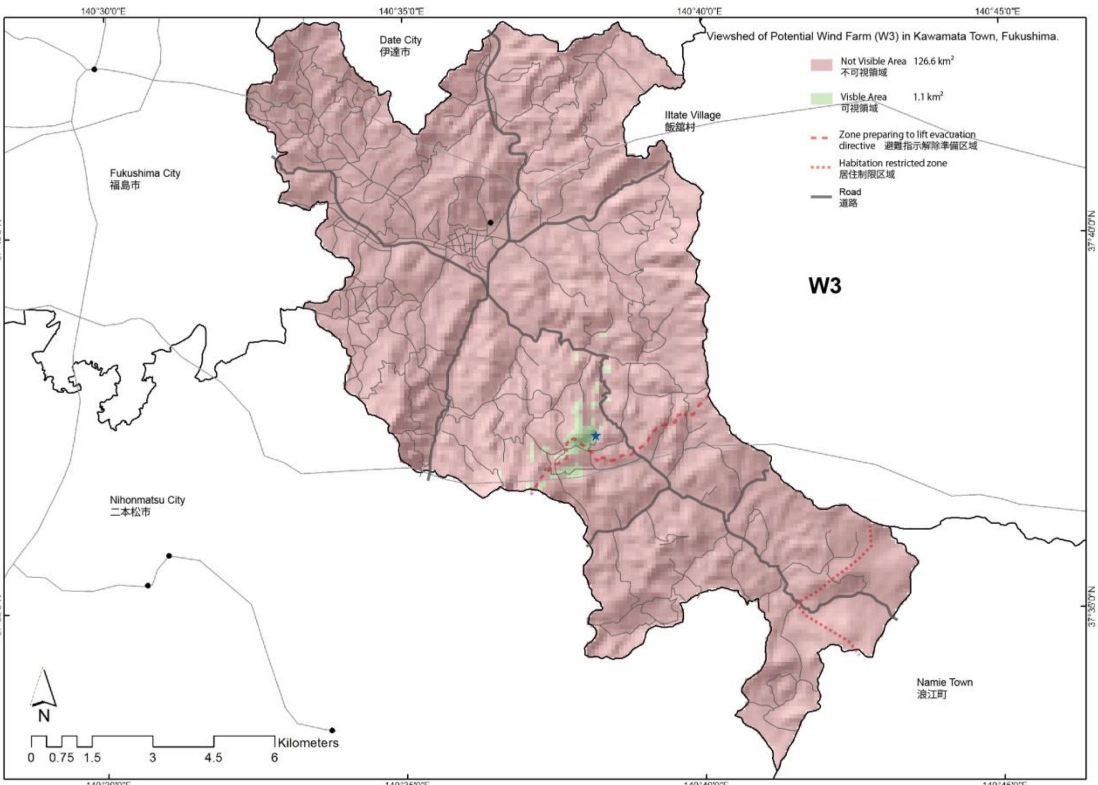


Figure 79. Viewshed maps of wind farm potential sites W3. (Source: by author).

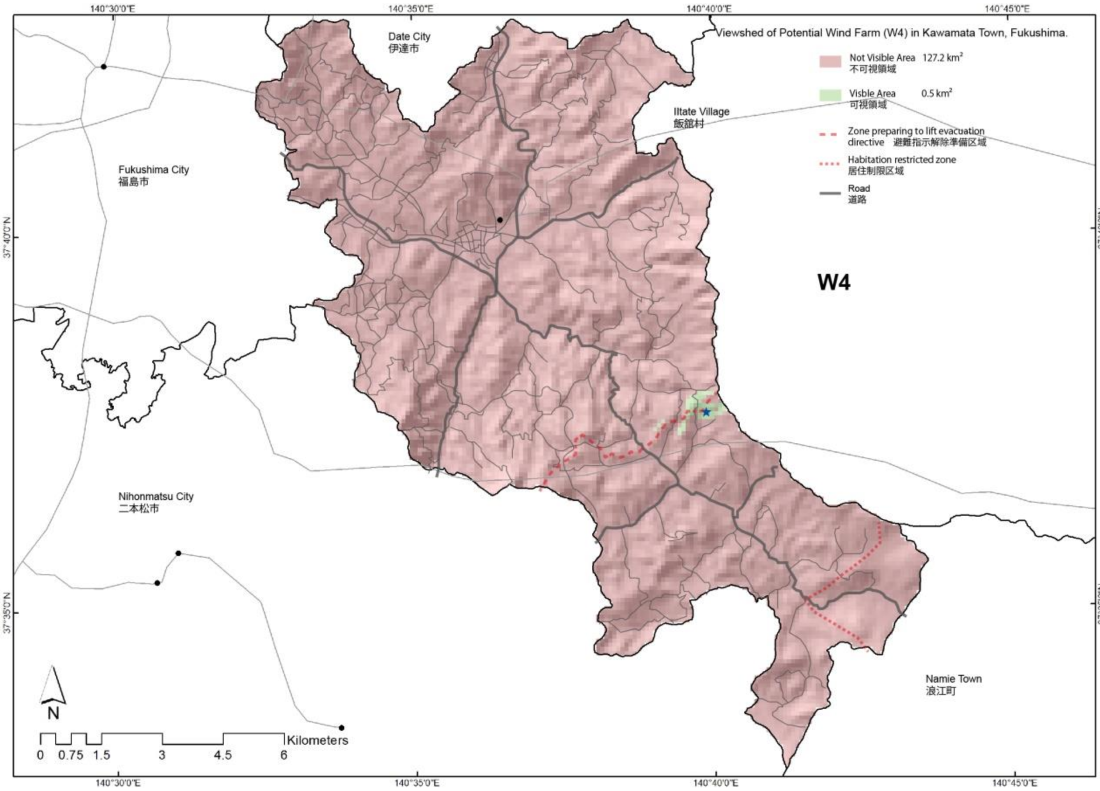


Figure 80. Viewshed maps of wind farm potential sites W4. (Source: by author).

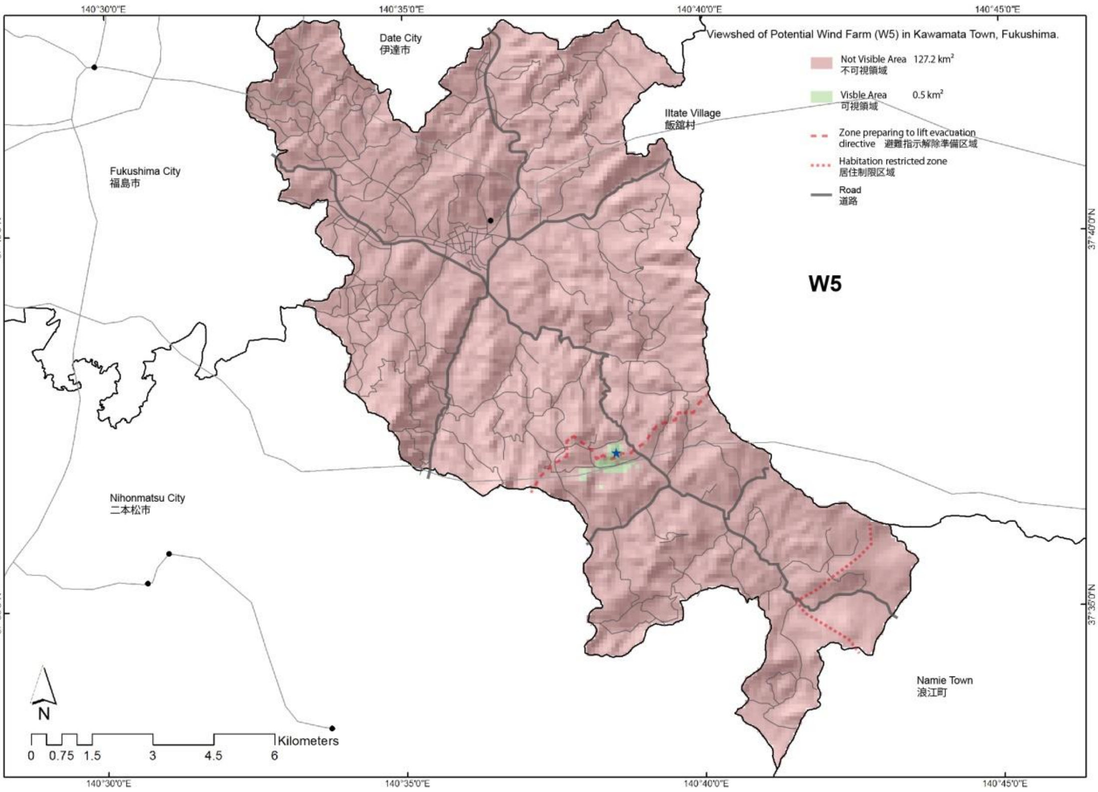


Figure 81. Viewshed maps of wind farm potential sites W5. (Source: by author).

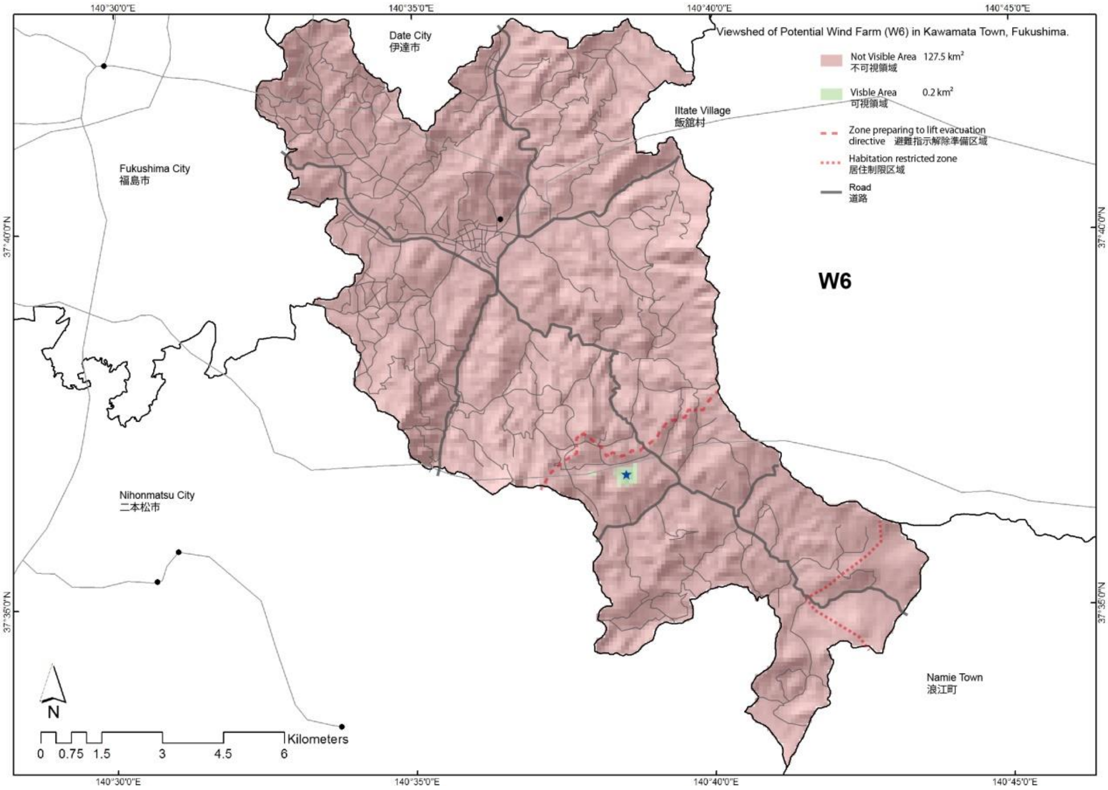


Figure 82. Viewshed maps of wind farm potential sites W6. (Source: by author).

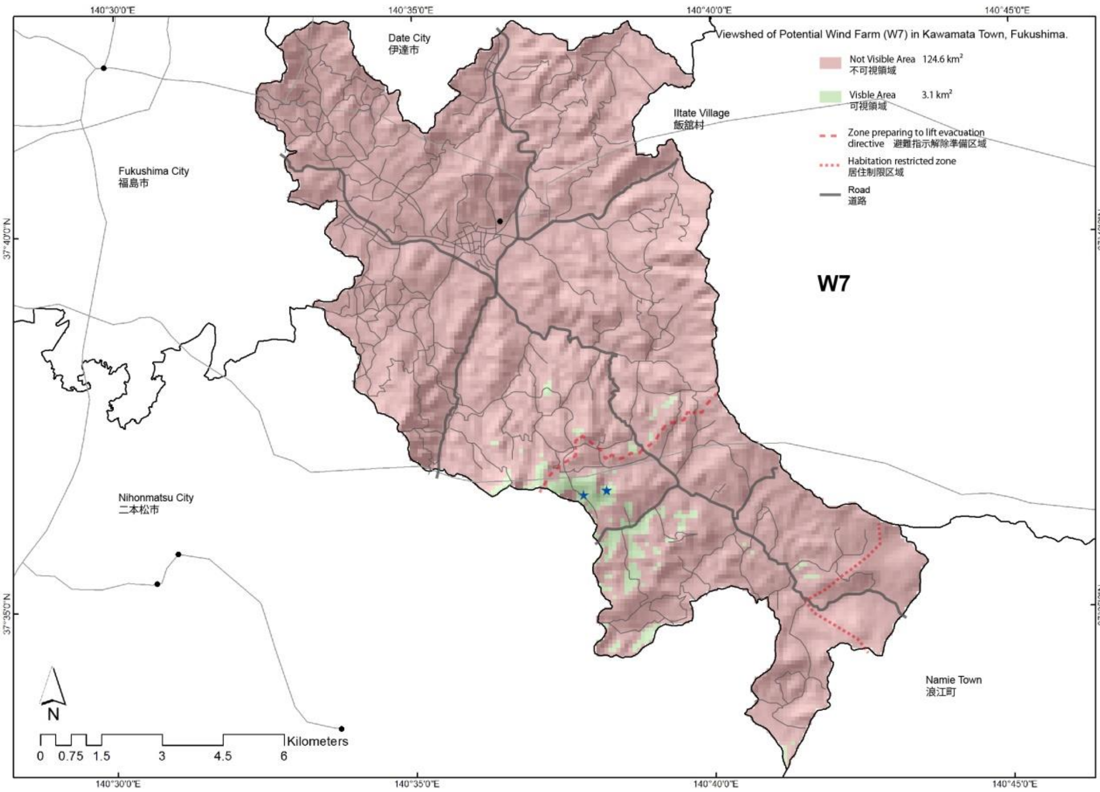


Figure 83. Viewshed maps of wind farm potential sites W7. (Source: by author).

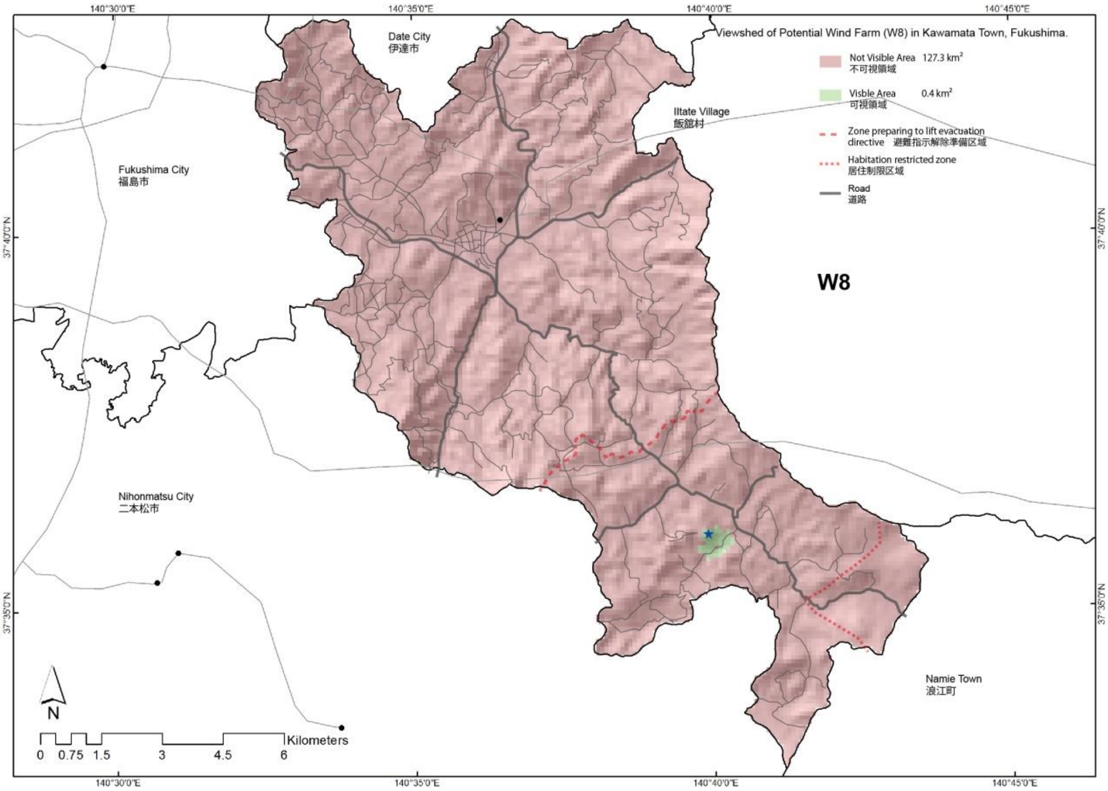


Figure 84. Viewshed maps of wind farm potential sites W8. (Source: by author).

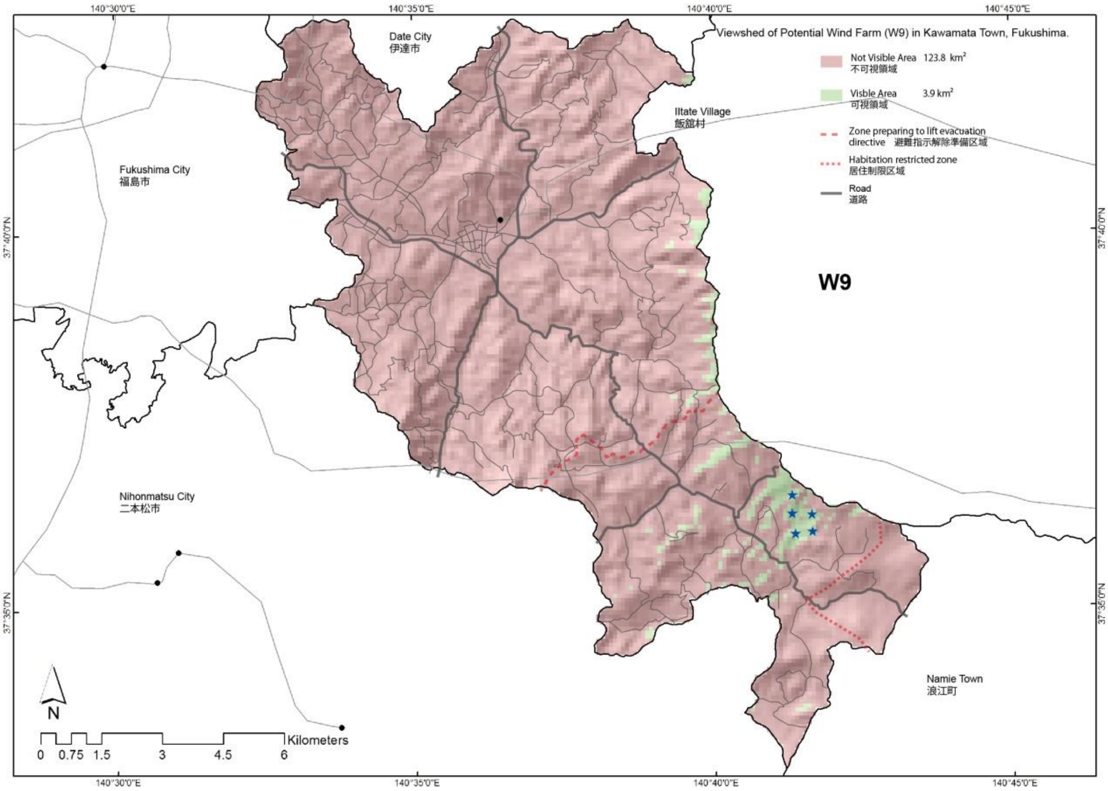


Figure 85. Viewshed maps of wind farm potential sites W9. (Source: by author).

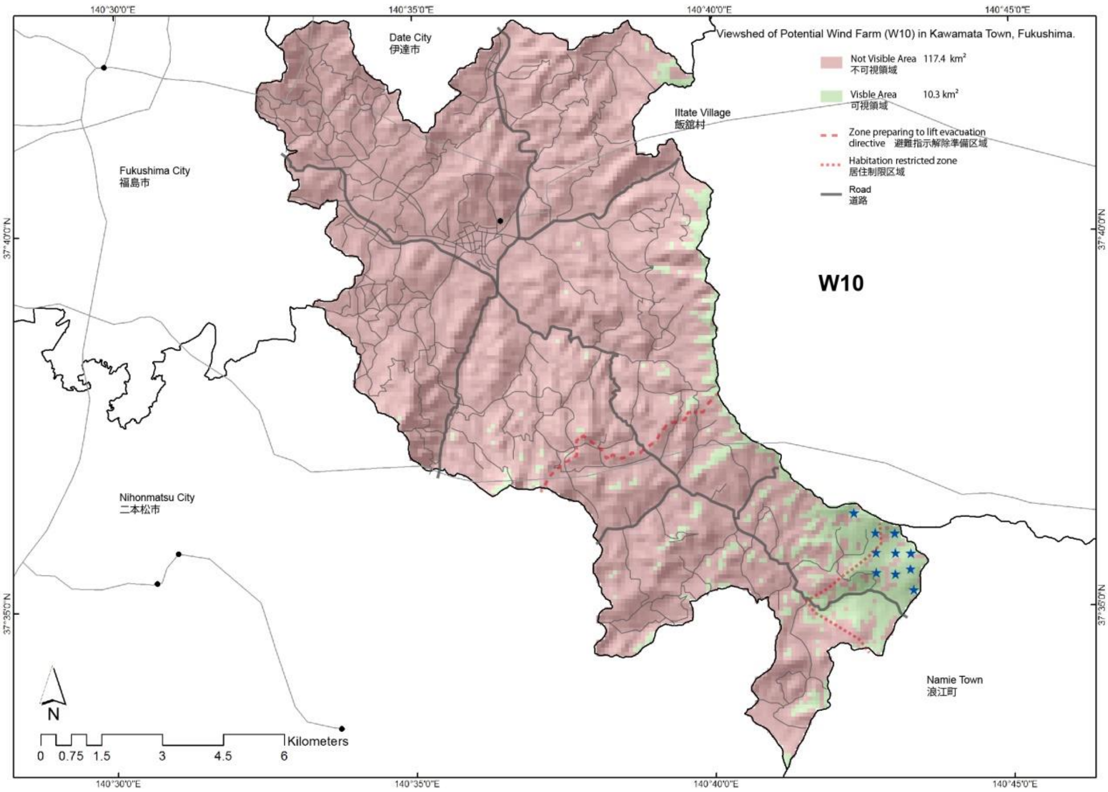


Figure 86. Viewshed maps of wind farm potential sites W10. (Source: by author).

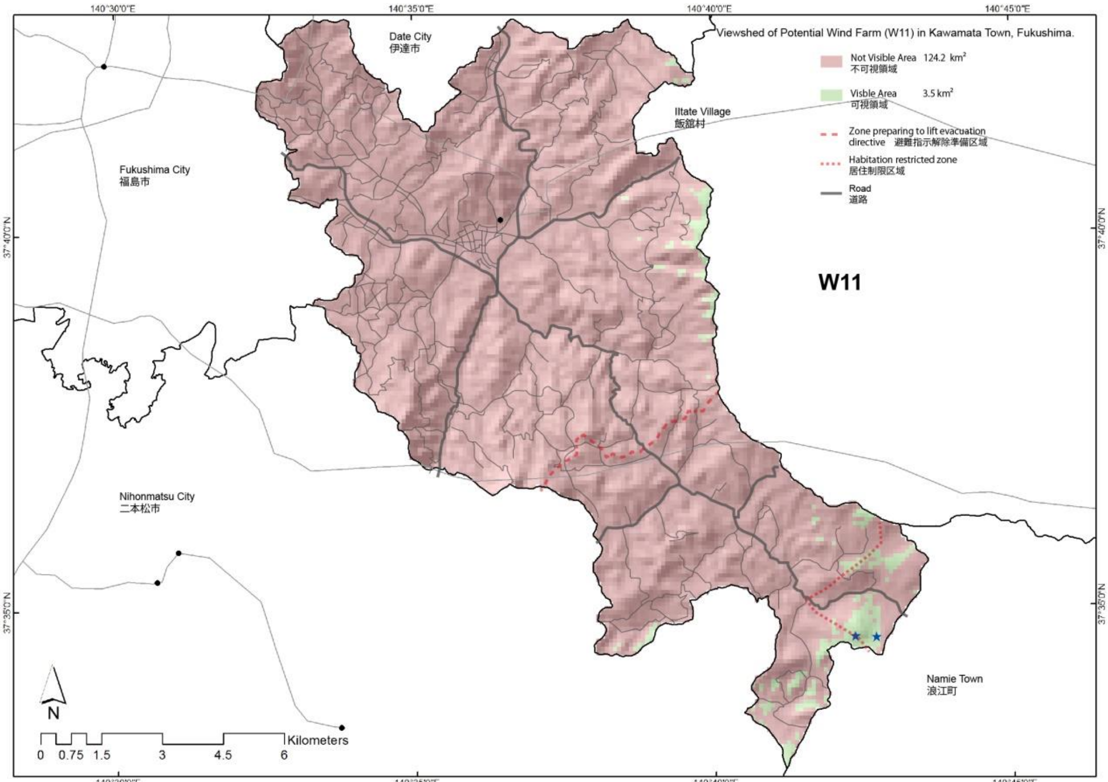


Figure 87. Viewshed maps of wind farm potential sites W11. (Source: by author).

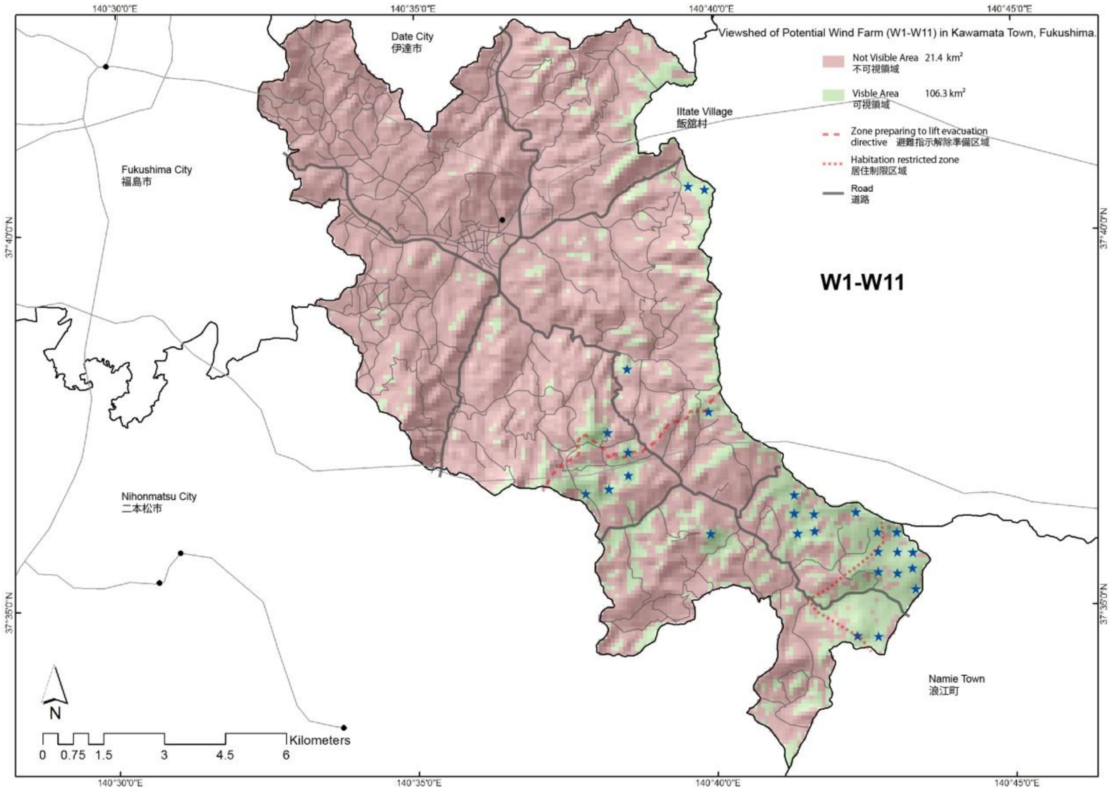


Figure 88. Integrated Viewshed maps of wind farm W1-W11.

Table 38. Detail information of potential site of mega-solar.

	Average annual solar radiation	Slope/Aspect	Available area(m^2)	Current land use	Capacity	Electricity production/year(Electricity selling income)	Access	Land use regulation(urban planning law)	Inside evacuative zones or not
S1	12.8 MJ/m^2-day	7.5° SW	21,976	Hybrid land(residence, agriculture field, forest)	2.8MW	3,449,774.9kWh*32=110 M JPY	Good	Outside urban planning area	No
S2	12.8 MJ/m^2-day	7.4° S	16,714	Hybrid land	2.1MW	2,623,750kWh*32=83.96M JPY	Good	Outside urban planning area	No
S3	13.0 MJ/m^2-day	7.8° W	26,157	Forest, agriculture field	3.3MW	4,170,262kWh*32=130M JPY	Good	Outside urban planning area	No
S4	13.3 MJ/m^2-day	7.8° SE	19,984	Factory, decontamination working space	2.6MW	3,259,614kWh*32=100M JPY	Good	Outside urban planning area	Yes
S5	13.2 MJ/m^2-day	6° S	48,185	Forest, decontamination working space	6.2MW	12,768,540kWh*32=410M JPY	Good	Outside urban planning area	Yes

Footnote: Annual electricity consumption was about 106,000MWh in Kawamata. Within which, basic electricity consumption was about 32,000MWh (about 30%).

Table 39. Detail information of potential site of wind farm.

	Average annual wind speed at 70m	Slope	Current land use	Number of 2MW wind turbines that can install	Electricity production/year (Electricity selling income)	Access	Distance from closest residential area	Viewshed Visible (not-visible) (km^2)	Land use regulation(urban planning law)	Inside evacuative zones or not
W1	7-7.3m/s	13.3°	Forest	2	7,708,800kWh/170 MJPY	Good	1200m	Visible3.5 (124.2)	Outside urban planning area	No
W2	7 m/s	4.5°	Forest	1	3,854,400kWh/84.8 MJPY	Good	700m	Visible0.5 (127.2)	The same	No
W3	7.2 m/s	4.2°	Forest	1	3,854,400kWh/84.8 MJPY	Good	560m	Visible1.1 (126.6)	The same	No
W4	7.4 m/s	8°	Forest, houses	1	3,854,400kWh/84.8 MJPY	Good	735m	Visible0.5 (127.2)	The same	Yes
W5	7.3 m/s	2.9°	Forest	1	3,854,400kWh/84.8 MJPY	Good	350m	Visible0.5 (127.2)	The same	No
W6	7.4 m/s	4.6-6.9°	Forest	1	3,854,400kWh/84.8 MJPY	Medium	715m	Visible0.2 (127.5)	The same	Yes
W7	7-7.3 m/s	2.8-8.9°	Forest, houses	3	11,563,200kWh/250 MJPY	Good	740m	Visible3.1 (124.6)	The same	Yes
W8	7.1 m/s	7.3-8.8°	Hybrid land (residence)	1	3,854,400kWh/84.8 MJPY	Good	860m	Visible0.4 (127.3)	The same	Yes
W9	7.2-7.4 m/s	3.9-8.5°	Forest and houses	5	19,272,000kWh/420MJPY	Good	1560m	Visible3.9 (123.8)	The same	Yes
W10	7.1-8.2 m/s	2.8-13.7°	Forest, decontamination working space	10	38,544,000kWh/840 MJPY	Good	3700m	Visible10.3 (117.4)	The same	Yes
W11	7.5-8.2 m/s	8.5-13.9°	Forest	2	7,708,800kWh/170 MJPY	Medium	1500m	Visible3.5 (124.2)	The same	Yes
W1-11	-	-	-		-	-	-	Visible106.3 (21.4)	-	-

Table 40. Detail information of potential site of biomass plant.

	Available biomass resource area (forest/agriculture land)	Current land use	Annual heat production GJ/yr.(Electricity selling income)	Distance from biomass resource area	Distance to energy supply area	Access	Land use regulation(urban planning law)	Inside evacuative zones or not
B1	571,089m^2; 10,290,033m^2	Hybrid land (agricultural land)	27995GJ+28902GJ=56897GJ/yr (380M JPY)	1500-3000m	500-3500m	Good	Non-senbiki urban area	No
B2	2,851,949m^2 5,801,903m^2	Forest, Agriculture land	13294GJ+17364GJ=30658GJ/yr (200M JPY)	1500-2000m	500-3000m	Good	Non-senbiki urban area	No
B3	1,266,171m^2 18,425,123m^2	Agriculture land	5637GJ+ 18838GJ=24475GJ/yr(160M JPY)	500-3000m	500-2500m	Good	Outside urban planning area	Yes

The interview results show that, the main issue in Kawamata is the Yamakiya area (composing about a 30% area of Kawamata town). Yamakiya area includes two types of evacuation areas within the boundary. One is the habitation restriction zone (not accessible), another is the “zone preparing for lifting off the evacuation directive”. People who used to live in the above two areas are living in temporary houses or have evacuated to other areas. Although the decontamination work is under progress (Figure 89), the fear of radiation, lifestyle changes, incomplete medical care, and other problems, brings high uncertainty of peoples’ return to the area.

Besides the above problems, after these areas were assigned as evacuation zones, most adults who used to live with their parents and children (three-generation family) moved out to other areas. Thus, the previous three generation family lifestyle was broke down, and only aged people (people elder than 80) are left, living in temporary houses. The Japanese Government wants to finish the decontamination work in Kawamata before August, 2014. After the decontamination, it is important to think about the re-building and revival of the Yamakiya area. How to re-build safe and convenient infrastructure, provide enough job opportunities for young people, and increase communication chances for aged people, are also current issues that are being addressed.

The Kawamata Government is now collaborating with Toda Corporation for post-disaster reconstruction. They proposed a “Depopulation Type of Smart Community” (Kawamata Gov., 2012) as the future development concept for Kawamata town. Under the concept, they are planning to revive the town with the help of RE to build a more sustainable community, as well as recover local agriculture business. With regard to the implementation projects under the concept, they proposed to build five 2MW wind turbines, six 1MW mega-solar farms, 6.5MW of rooftop solar panels, and a biomass heat supply agriculture farm. However, local people are very apprehensive about accepting these projects, because they are worried about the high operation cost of these RE facilities.

There are several potential sites for mega-solar, wind turbine development, and biomass resources. As one alternative use of land in evacuation areas, mega-solar maybe a good choice. This could bring income for land owners and the possibility to sell electricity for stakeholders. For wind turbines, visual impact and noise problems should be carefully investigated, and their layout should also be carefully planned. For biomass heating supply, monitoring will be necessary, because of the radiation issues in the area. Because heat can only be transferred within a limited distance, biomass heating supply could be combined with new public housing plans to provide heat and hot water for them. Furthermore, radiation prediction is necessary as well, to show which areas are available for biomass resource supply in the future. Once the radiation level drops, forests will be available for biomass energy production. Using local resources (residue) will further improve local sustainability.

Figure 89. Decontaminating working area and temporary houses in Kawamata town.

(Source: by author).

4.5.6 Decision Making Support: from Potential Estimation to Spatial Planning for Renewable Energy

This study takes a step forward from potential estimation of RE, tries to facilitate spatial planning of RE on the basis of potential estimation. Following the proposed approach, objective statistics and visualized maps can be generated and provided for integrated decision making. Table 41 shows the information that each proposed approach provided for decision-making support in the process of spatial planning for RE. In this way, the proposed approach explored a way from RE "potential estimation" to decision making support of "spatial planning for RE".

Table 41. Information that each steps provided for decision making support in the process of spatial planning for RE.

Steps in Approach	Spatial planning for RE	Spatial scale
Potential Estimation	• Theoretical potential • Available potential, and • Available sites	Regional
Energy Self-sufficiency Map	• Spatial energy flow direction: High-Medium-Low energy self-sufficiency areas • Energy demand-supply relationship • Future energy self-sufficiency possibility	Regional
Composite Map	• Spatial distribution: RE potential sites • Urban planning relationship • Heat supply radius	Regional
Scenario Analysis	• Input-output relationship, comparison • Priority RE development areas	Regional
	• Detail information of each possible site (slope, aspect, access, land use etc.) • Current local issues • Viewshes analysis for possible visual impact areas by wind turbine	Municipal

Decision Making Support	• Statistics and visualized maps • Possibility to combine with local housing plan, land use, transportation plan, and industrial park plan etc.	Regional and Municipal

4.6 Discussion

Based on the above findings, this study 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 (2008) 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 (Sarafidis et al., 1999; Stremke and Koh, 2010), 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 (Rio and Burguillo, 2008; Bergmann et al., 2011) 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.

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

6.1 Conclusion.

6.1.1 Renewable Energy and Sustainability

Based on the findings and discussions in Chapter 2 Section 2.4, conclusions for the relationship between RE and sustainability can be made as follows.

Multiple factors are necessary for local RE promotion. While RE do not poses equal values in supporting local sustainability.

6.1.2 Renewable Energy and Landscape: Visual Impact Evaluation of Wind Turbine.

Based on the findings and discussions in Chapter 3, conclusions for case study in Choshi city can be made as follows:

1) The proposed methodology has been successfully applied to the study area. An intergraded wind farm planning at the both city and community scale should be a key consideration for future cities. Careful planning of wind turbines and layout considerations at a local landscape scale can reduce its visual impact, while topography should be used to mask wind turbines.

2) Spanish method is easy and quick to apply at the community level in Japan. However, modifications and improvements are needed, which can be made as follows: i). a solution to the cumulative impact calculation in case of multiple wind farms around one target settlement should be provided. ii). Adjustments of coefficients calculation method and evaluation criteria to suit different geographical and social contexts are necessary. iii). Add coefficients for different landscape types where the wind farm is located. iv). Provide a solution for the coefficient 'c' calculation, when a wind farm is in a random layout that cannot be easily taken as a cuboid.

3) The placement of wind turbines close to residents' living quarters such as residential and urban areas should be avoided, because wind turbines located in residential and urban areas are most likely to influence residents' perception. If unavoidable, visible turbine numbers from one viewpoint should be less than five. When planning for wind turbines, careful visual impact evaluation for different layout scenarios is recommended. The use of one line layout should be minimized, because one line layout is likely to have stronger visual impact to the landscape compared to grid (two lines) and random layouts.

6.1.3 Renewable Energy and Spatial Planning: Concept and Approach

Based on the findings and discussions in Chapter 4, conclusions can be made as follows:

1) 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 0.1μSv/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.

2) 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.

3) 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.

4) 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. This study reckons that municipalities and communities shall be best informed through GIS-based integrated analysis, and hence make the most appropriate decisions in the planning process.

6.2 Future Tasks and Recommendation.

Although wind energy is being developed at a fast rate in some Asian countries such as China, India, and Japan (Global Wind Energy Council, 2011), visual impact related research is still less than in European countries or in the United States. It has only been carried out in some basic studies such as public attitude and perception survey on wind energy planning and implementation procedure. In the future, there is a need to focus on these fundamental studies that can evoke research awareness on visual impact of wind farms, as well as to develop an objective and accurate evaluation methodology and criteria suitable for Asian countries. This study highlights that attention should not be paid to wind farms in high scenic value areas only; it should also be directed to the local community areas and settlements.

Furthermore, this study argue that some basic concepts of spatial planning, such as spatial organization for future activities distribution, consideration for balancing spatial development with social, economic, and ecological requirements are applicable in the RE planning field too. As discussed in Chapter 4, Section 4.7 (Discussion). This study recommends several guidelines that should be considered in the RE spatial planning process. They are:

1) Sustainability: thinking about the future, and long-term development;

2) Energy flow: energy flow can be flexibly planned for, between low self-sufficiency and high self-sufficiency areas based on actual condition;

3) Energy efficiency and distance: we may plan for efficient energy transfer through appropriate spatial organization. Because heat can only be transferred within a limited distance, heat supply system can be planned combing with other plans, such as: housing and industrial park plan among others.

4) Impacts and benefits: this study emphasized “Visual Impact” of the increasing scale and

number of RE facilitates, especially wind turbines. Also, benefits include increase energy independency (Takigawa et al., 2012; Tsoutsos, 2005), job creation benefits (Rio and Burguillo, 2008; Bergmann et al., 2011) and so on. This study recommends that in the future, regional or city scale comprehensive evaluation should be considered or integrated in the RE spatial planning process, thus to balance social, economic, and environmental requirements for different regions or areas.

5) Public participation: it is an important part of spatial planning. Different from current centralized energy supply system, RE provide another choice, decentralized energy system to the public. The characteristics of decentralized energy systems allow more people to be involved in. The public can generate, choose, and use the sustainable energies as they like. The public and community can develop local energy system using technologies, such as Smart Grid, to improve or achieve local "Energy Autonomy (Energy Self-sufficiency)". As more and more people involved in, the current energy system can be transformed into a more sustainable system, a green, open, smart, and safe system.

Although many countries' national energy policies are still focusing on conventional energy generation and supply system, we can gradually change current situation by the "bottom-up" approach-public participation. The achievements of this study can be used in participatory process for RE planning by providing informative and visualized information to the public. Analysis such as scenario analysis can provide alternatives for local people, and detail data of potential RE sites. These could help with the decision making in the planning process, and then guide the planning implementation. Also, Web-based GIS can provide an interactive platform and information-gathering hub for public, investor, policy maker, and planners.

Specifically, the above ideas can be simplified to Figure 90.

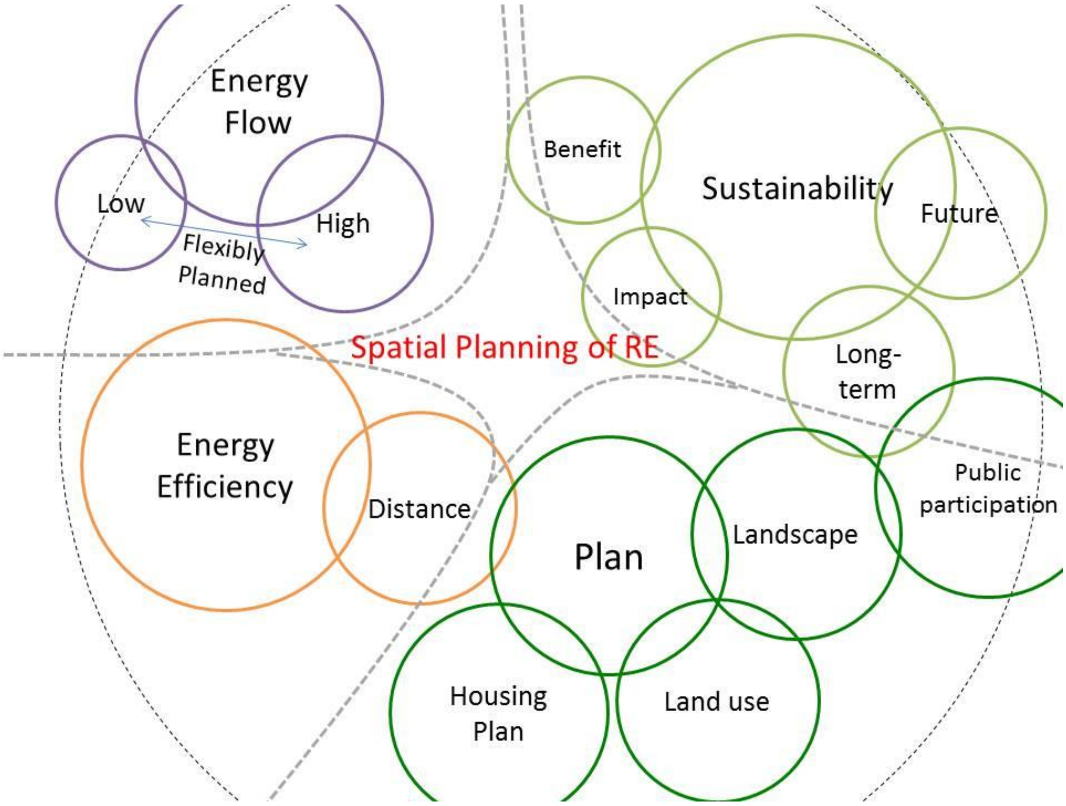

Figure 90. Significant aspects and factors of Spatial Planning for Renewable Energy.

(Source: by author).

Nonetheless, this study has improvements that need to be done in the future. Through this study, some future tasks have been identified. They include:

1) The proposed methodology for visual impact evaluation and the proposed approach of GIS-based spatial planning for RE only have one case study respectively. In regard to the spatial planning inclusion into RE planning, the future tasks of this study rests on conducting more case studies in different countries and regions, so that the proposed methodology and approach can be further adjusted into a more flexible level for different places.

2) GIS-based evaluation methods to identify optimal locations for large-scale RE facilities, visual impact evaluation, and scenario analysis have its own limitations as well, such as detail missing, weak ability in real scene quality evaluation and so on. To solve these problems, the next phase after GIS-based analysis and evaluation should be on-site field survey, as well as local people interview, and perception survey etc.

3) This study only conducted preliminary study on key factors for local RE promotion and RE's sustainability value. As mentioned in Section 2.4, much emphasis has been put on RE's environmental contribution, in contrast, the researches on its socio-economic benefits have been lacking. Which remains as future tasks for RE and sustainability research field.

4) This study reveals potential for the multi-discipline between RE, Spatial Planning, and Landscape Architecture. Right now, this inter-discipline research field (Figure 91) has not been aware of. The full introduction of GIS-based approach in support of spatial planning for RE has not been well utilized, mainly due to lack of multidisciplinary knowledge and know-how between spatial planning and energy planning fields. This combination also put a new challenge for landscape architecture professional field. Therefore, we need to evoke research awareness on this topic, where more multi-discipline knowledge, theories, application cases will be needed in the future. So that we can shift the current status from "Research" to real "Practice".

Today, the world is gradually transforming into post-fossil fuel society, the low-carbon, new energy supply and consumption system and facilities is developing at a quick pace. In the meantime, peoples' lifestyle and energy awareness is also changing, such as more and more people choose bicycle as their first choice for commuting instead of private cars, the wide spread of car-sharing concept around the world, the quick development of Electric Car (E.V) maker-Tesla Motors, Inc., and the increasing of E.V charging piles around the world. In order to change the energy structure and people's mind gradually, we may establish a RE-based lifestyle (Figure 92), so that our living, working, moving etc. can be connected with sustainable energy resources.

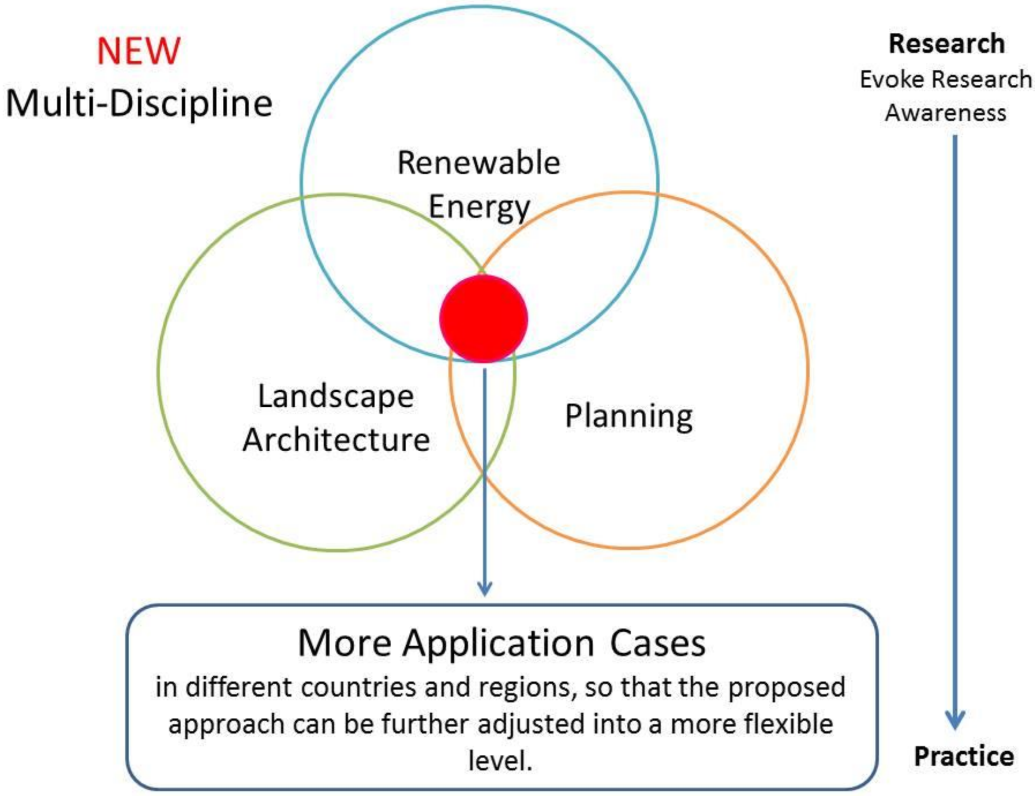

Figure 91. New multi-discipline field composed by Renewable Energy, Landscape Architecture, and Planning. (Source: by author).

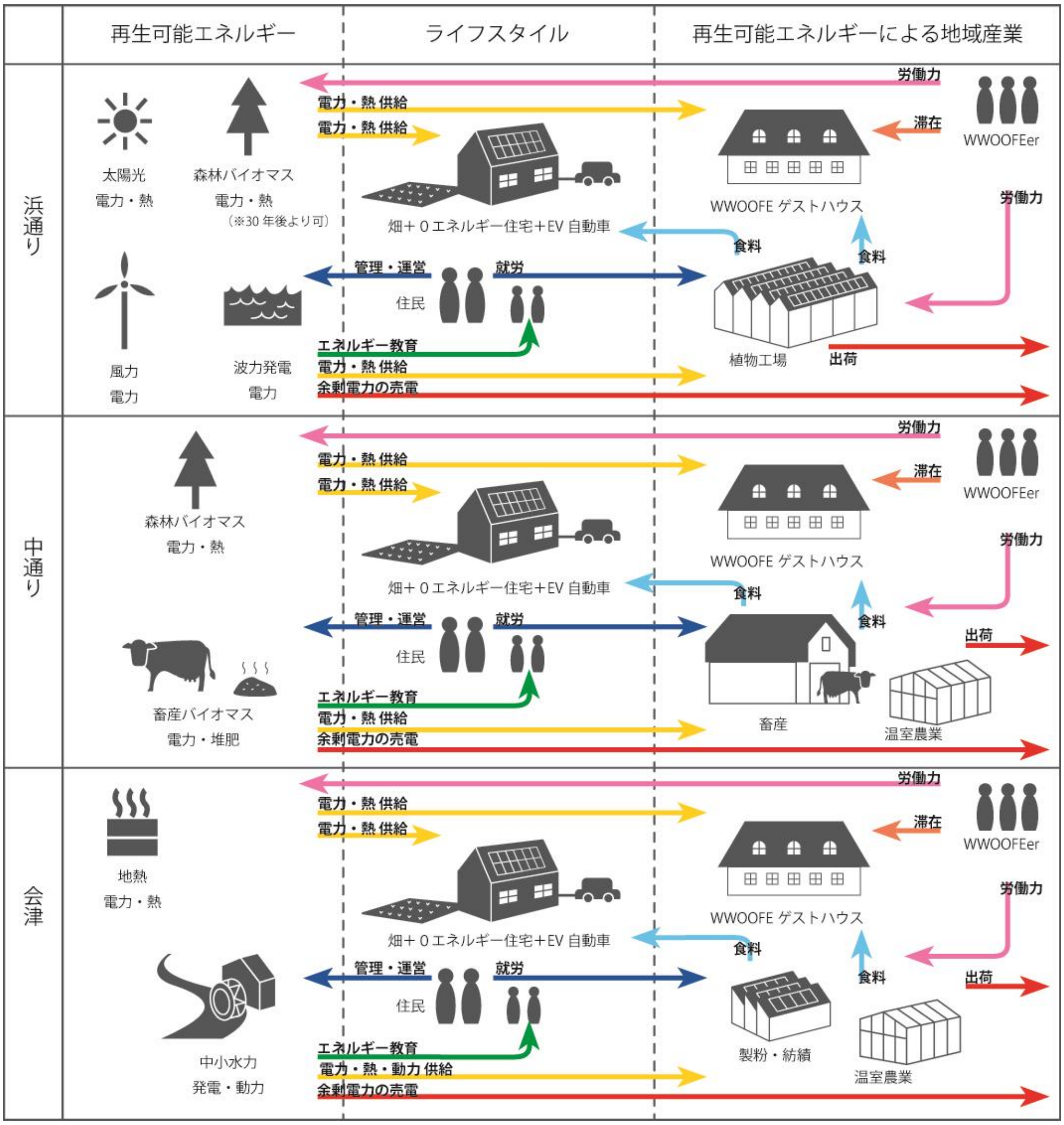

Figure 92. A sample proposal in Fukushima for new social and lifestyle based on different renewable energy sources for future sustainable development. See detail in Appendix 9. (Source: by Aiko Kimura, Qianna Wang, Isami Kinoshita, 2014)

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APPENDIXES

- **Appendix 1: Relative Information, Interview Record of Schaffhausen, Switzerland.**
- **Appendix 2: Questionnaire Sheet in Choshi City, Japan.**
- **Appendix 3: Wind turbine information in Choshi, City.**
- **Appendix 4: Original Data Record for Visual Impact Evaluation Matrix in Spanish Method.**
- **Appendix 5: Interview Record in Choshi City, Japan.**
- **Appendix 6: Questionnaire Sheet in Kuzumakicho, Japan.**
- **Appendix 7: Questionnaire Sheet in Chongming Island, China.**
- **Appendix 8: Current RE facilities in Fukushima, Japan.**
- **Appendix 9:**「第１回福島県再生可能エネルギー普及アイデアコンテスト」応募作品

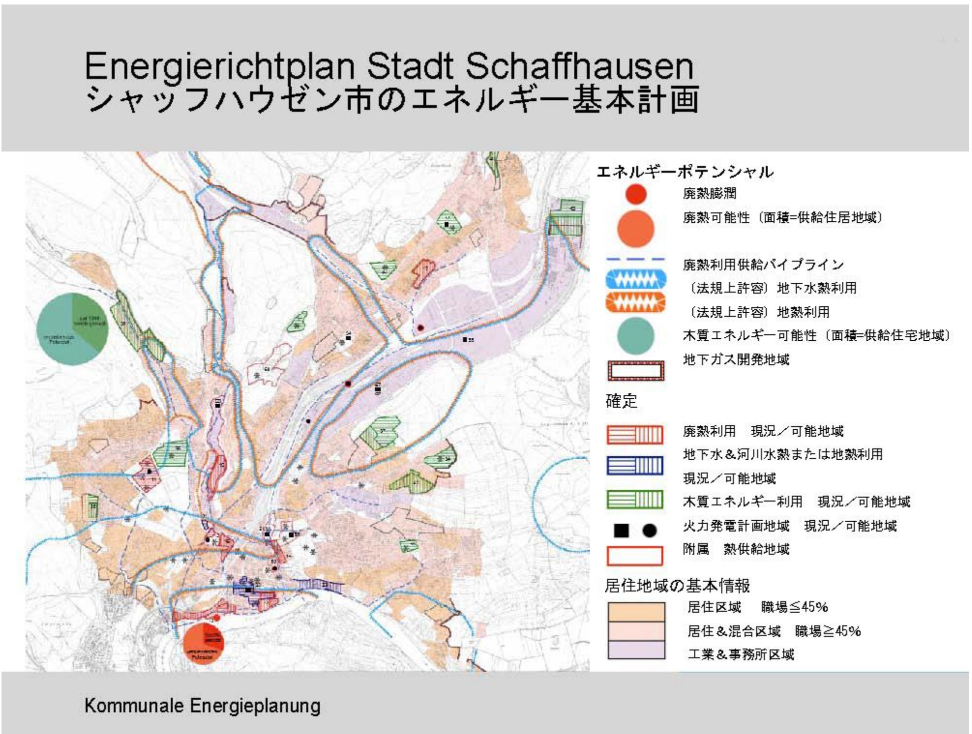
Appendix 1: Information and Interview Record of Schaffhausen, Switzerland.

Schaffhausen, Switzerland.

1. Location: North of Swiss. Next to Germany and Austria. By Rhine River.

Area: 31km^2; Population: 35,000; Industry: High-tech, watch manufacturing, tourism in the future.

2. Schaffhausen's Energy Planning (2007)



Source:http://www.stadtschaffhausen.ch/fileadmin/Redaktoren/Dokumente/Umwelt_Energie/Strahlungsenergie_Stadt_Schaffhausen.pdf. (木下訳)

Main Features:

-Energy planning also connected to transportation planning in Schaffhausen

- Biggest renewable energy potential: Solar energy & Hydropower.

- About solar energy: need to search for suitable roof. Generally, 80% of building can be used, but historical building's conservation issues exist.

- About hydropower: has even bigger potential than solar power in Schaffhausen

- Few geothermal potential

Interview

1) On site interview: 2011.6.28, 9:00 — 11:00.

With City Ecologist officer: Mr. Urs Capaul; Urban planning dept. officer: Mr. Walter Herrmann.

2) Mail Interview: 2012.3.21

With City Ecologist officer: Mr. Urs.

Mail Interview Records

Two topics: 1) Schaffhausen's energy planning procedure; 2) Planning methodology.

1) Schaffhausen's energy planning procedure.

Q1: This energy plan was made in 2007, is there any new progress of it?

A: We revise our energy plan this and next year, because we like to introduce a reduction path to a 2000-Watt-Society.

Q2: Each steps to make the plan?

A: Step 1. Necessary data collection and calculation

Step 2: Define high heat potential location.

- Define locations with higher heat potential that can be used for a decentralized heating system or a heating network.

Step 3: Define ground water protection area.

-Define the groundwater protection area, because there is no use of geothermal allowed.

Step4: Implement the energy plan.

-Implement the plan: there is a municipal law, that requests: energy using has to follow the energy plan!

Q3: What data is needed for the plan?

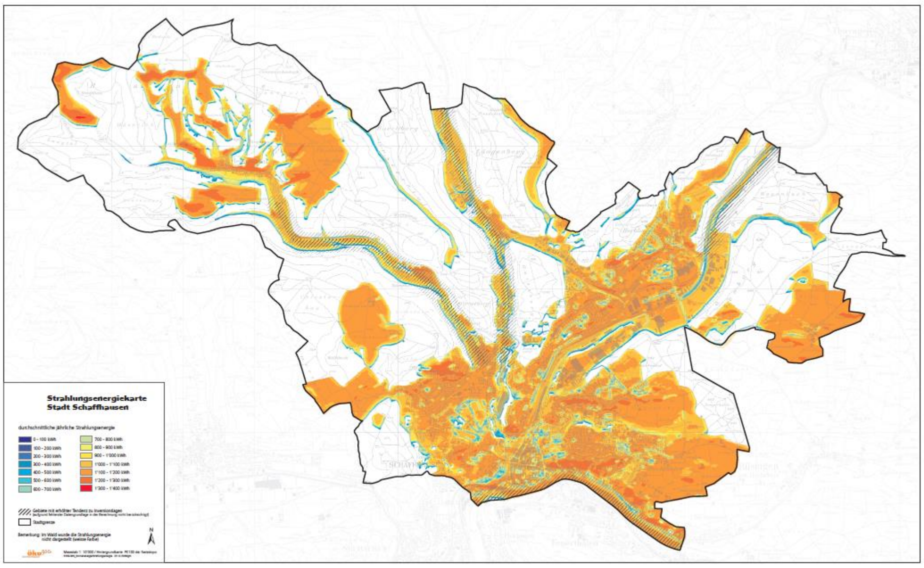
A: Data we need for the energy plan:

1.the current energy consumption of all buildings, particularly of the public buildings. The energy consumption has to be shown with all energy sources.

2. We also need the usable waste heat (for example of the generator in a hydroelectric power station or of the sewage channels) and the potential of wood energy and other renewable energy sources (except solar energy, because this source is widely available and needs no spatial planning).

3. The biomass potential capacity is calculated via annual woodcut, because this is the only biomass resource we have on the urban area.

4.Solar energy: we calculated the usable energy density of each place in town and we plotted it on a map.



Source:http://www.stadtschaffhausen.ch/fileadmin/Redaktoren/Dokumente/Umwelt_Energie/Strahlungsenergie_Stadt_Schaffhausen.pdf.

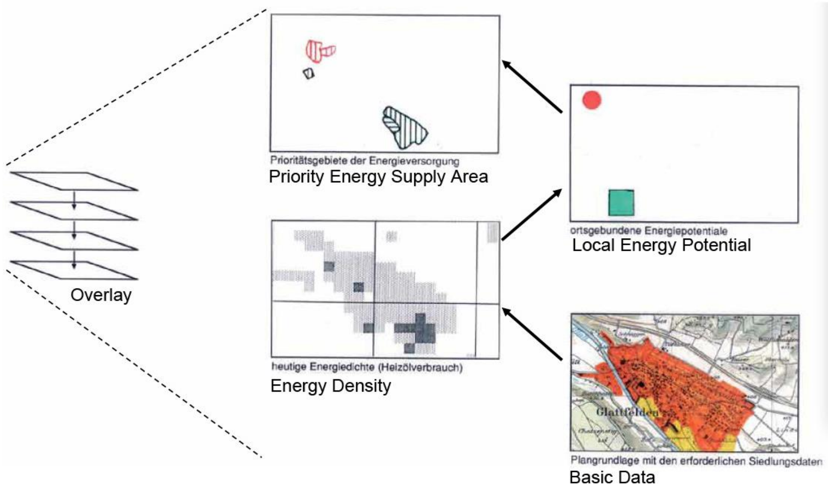
Q4: How the potential capacity, for example, biomass potential capacity was calculated?

A: The biomass potential capacity is calculated via annual woodcut, because this is the only biomass resource we have on the urban area. Solar energy: we calculated the usable energy density of each place in town and we plotted it on a map

Q5: How is the planning taking into practice right now? (Since the plan was made in 2007)

A: Implement the plan: there is a municipal law, that requests: energy using has to follow the energy plan!

2) Planning Methodology.



Source: Bruno Hoesli, 2010,Kommunale Energieplanung

Q1: What is the exact meaning of each data layer?

A: Energy potential layer means: the actual existing energy of waste energy and all renewable energy sources from any location in the city. This is the energy that can be used on site, in addition to the conventional fuels. (You need accurate and detailed data)

Energy density layer means: the actual energy demand on site. (You need accurate and detailed data).

Comparing these two layers you see, which part of energy you can cover on site with renewable energy sources.

Priority energy supply area layer: In general, you have different energy sources on site (e.g. conventional fuels like liquid gas, natural gas or heating oil) that are in competition with renewable energy sources. So you have to prioritize the best kind of energy, especially if you want to promote renewable energies. So, that is, what you are doing in this step.

Q2: How were the potential areas were found out?

A: By comparing different data layers and do overlay analysis.

Appendix 2: Questionnaire Sheet in Choshi City, Japan.

「大型風力発電所地域集落への景観視覚影響　アンケート調査」

あなた自身についてお聞きします

（記入の仕方：あてはOをつけてください）

1. 性別　　男 · 女

2. 年齢　（　　）代　前半・後半

3. 職業

· 勤め人　· 自営業　· 農業　· 漁業　· 家事専業

· パート、アルバイト　· 学生　· その他（　　）

4. お住まい　〒(　　ー　　)　銚子市(　　)町　その他(　　)

5. あなたは永久の住民ですか。　はい · いいえ

居住年数：　· 1 年以下　· 1ー5 年間　· 5ー10 年間

· 10ー20 年間　· 20 年間以上

風力発電の全般についてお聞きします

1. あなたは再生可能エネルギーのプロジェクト（風力発電所、太陽光発電所、水力発電ダムなど）についてどう思いますか。

· かなり賛成　· やや賛成　· どちらでもない　· やや反対　· かなり反対

2. 他の再生可能エネルギーと比べて、風力発電のプロジェクトについてどう思いますか。

· かなり賛成　· やや賛成　· どちらでもない　· やや反対　· かなり反対

3. 他の発電施設と比べて、風力発電のメリットは何と思いますか。（複数選択可）

· 環境にやさしい　· 用地が少ない　· 独特の風景を創出する

· 観光価値あり　· その他（　　）

4. 他の発電施設と比べると、風力発電のデメリットは何と思いますか。（複数選択可）

· 目立つ　· 騒音が大きい　· 鳥類など動物への影響が大きい

· 人の健康への影響が大きい　· 電波障害が大きい　· その他（　　）

5. 銚子の風車の建設前、建設中、建設後、風力発電所への考えはどうでしょうか。

建設前:　かなり賛成　やや賛成　どちらでもない　やや反対　かなり反対

建設中:　かなり賛成　やや賛成　どちらでもない　やや反対　かなり反対

建設後:　かなり賛成　やや賛成　どちらでもない　やや反対　かなり反対

6. 風車を建設前と建設後と比べて、一番大きな影響は何と思いますか。（一つ選んで下さい）

· 騒音　· 地形、地質　· 動物（鳥類など）　· 植物　· 電波障害

· 生態系　　· 日照阻害　　· 景観　　· 人と自然との触れ合いの活動の場

7. その影響の程度はどのくらいと思いますか。
· かなり強い　　· やや強い　　· 普通　　· やや弱い　　· かなり弱い

8. 風車の建設を始める前に、事業者から地元住民に対して説明会が行いましたか。
· はい　→（　参加した・参加しなかった　）　　·　いいえ　　·　分らない

9. もしこれからお住まいの付近で風車の建設予定があれば、あなたは賛成しますか。
· 賛成　　· 事業者ちゃんと説明してくれると、賛成　　· どうしても賛成しない

風力発電所の景観影響についてお聞きします

1. **普段、お住まいから、何基の風車をよく見えますか。**　　（　　　）基

2. お住まいから、一日で、風車を見る頻度は何回ですか。　一日（　　　）回

3. 普段、お住まいから見ると、風車は圧迫感がありますか。
· かなりあり　　· ややあり　　· 普通　　· それほどない　　· ほとんどない

4. お住まいから風車まで、どのぐらい離れていると思いますか。（おおよそで結構です）
· 0－500m　　· 500-1000m　　· 1000-1500m　　· 1500－2000m
· 2000m－2500m　　· 2500m 以上

5. 特に、風車を建設後、地元の風景の変化への影響はどの程度と思いますか。
· かなり強い　　· やや強い　　· 普通　　· やや弱い　　· かなり弱い

6. あなたにとって、地元の風景を壊さないため、風車は何基までをよいと思いますか。
· 5 基まで　　· 10 基まで　　· 15 基まで　　· 20 基まで　　· 25 基まで
· 30 基まで　　· 35 基まで　　· 35 基以上　　· 何基でも結構です

参考イメージ
○5 基　　○13 基　　○22 基



風車の配置についてお聞きします

背景は現地で撮った写真です。以下のイメージによって、風車の配置の景観への影響の強さについて近い考えのところに○をつけて下さい。

1. 配置の景観類型

①農地景観 ②住居景観 ③市街地景観

④道路景観 ⑤里山景観

①農地景観：	かなり強い	やや強い	普通	やや弱い	かなり弱い
②住居景観：	かなり強い	やや強い	普通	やや弱い	かなり弱い
③市街地景観：	かなり強い	やや強い	普通	やや弱い	かなり弱い
④道路景観：	かなり強い	やや強い	普通	やや弱い	かなり弱い
⑤里山景観：	かなり強い	やや強い	普通	やや弱い	かなり弱い

2. 配置形態（すべて 6 基です）

①一列配置 ②グリッド配置（2 列） ③ランダム配置

①一列配置：	かなり強い	やや強い	普通	やや弱い	かなり弱い
②グリッド配置：	かなり強い	やや強い	普通	やや弱い	かなり弱い
③ランダム配置：	かなり強い	やや強い	普通	やや弱い	かなり弱い

Appendix 3: Wind turbine information in Choshi, City.

Year	Wind farm	Number of wind turbine	Location Detail
2001	銚子屏風ヶ浦風力発電所	1 基	35°42′16.0″N, 140°46′26.0″E
2003	銚子小浜風力発電所	1 基	35°42′10.0″N, 140°46′6.0″E
	銚子しおさい風力発電所	2 基	35°42′28.0″N, 140°46′8.0″E 35°42′14.0″N, 140°46′3.0″E
2004	銚子風力発電所	9 基	35°43′24.0″N, 140°46′39.0″E 35°43′13.0″N, 140°46′45.0″E 35°43′14.0″N, 140°47′5.0″E 35°43′17.0″N, 140°47′26.0″E 35°43′28.0″N, 140°46′54.0″E 35°43′32.0″N, 140°47′11.0″E 35°43′32.0″N, 140°47′14.0″E 35°43′28.0″N, 140°47′12.0″E 35°43′27.0″N, 140°47′7.0″E
2006	銚子新町風力発電所	1 基	35°43′54.0″N, 140°45′34.0″E
	銚子高田町風力発電所	1 基	35°45′33.0″N, 140°45′10.0″E
	台町風力発電所	1 基	35°42′55.0″N, 140°49′29.0″E
	八木風力発電所	6 基	35°43′8.0″N, 140°44′23.0″E 35°43′19.0″N, 140°44′38.0″E 35°43′25.0″N, 140°45′9.0″E 35°43′10.0″N, 140°45′14.0″E 35°42′57.0″N, 140°44′56.0″E 35°43′17.0″N, 140°44′45.0″E
2007	銚子ウィンドファーム	7 基	35°44′41.0″N, 140°45′27.0″E 35°44′35.0″N, 140°45′31.0″E 35°44′19.0″N, 140°45′45.0″E 35°44′12.0″N, 140°45′17.0″E 35°44′11.0″N, 140°45′25.0″E 35°44′26.0″N, 140°45′42.0″E 35°44′33.0″N, 140°45′42.0″E
2009	椎柴風力発電所	5 基	35°45′24.0″N, 140°44′29.0″E 35°45′12.0″N, 140°44′39.0″E 35°45′28.0″N, 140°44′38.0″E 35°45′23.0″N, 140°45′2.0″E 35°45′8.0″N, 140°45′12.0″E

Source: Based on NEDO 風況マップ(http://app2.infoc.nedo.go.jp/nedo/webgis?lv1=03) and site survey.

Table for Turbine Information.

Year	Wind farm	Number of wind turbine	Wind turbine output	Wind turbine height	Blade diameter	Develop company	Location
2001	銚子屛風ヶ浦風力発電所	1 基	1500kw	65m	70m	日本風力開発(株)	銚子市小浜町
2003	銚子小浜風力発電	1 基	1500kw	65m	70m	日本風力開発(株)	銚子市小浜町
	銚子しおさい風力発電所	2 基	1500kw	65m	70m	明電舎(株)	銚子市親田町・常世田町
2004	銚子風力発電所	9 基	1500kw	65m	70m	日本風力開発(株)	銚子市柴崎町ほか
2006	銚子新町風力発電所	1 基	1980kw	64m	70m	堀江商店(株)	銚子市新町
	銚子高田町風力発電所	1 基	1990kw	64m	71m	くろしお風力発電(有)	銚子市高田町
	台町風力発電所	1 基	640kw	45m	44m	根徳商店(有)	銚子市台町
	八木風力発電所	6 基	1500kw	65m	70m	日本風力開発(株)	銚子市八木町
2007	銚子ウィンドファーム	7 基	1500kw	65m	70m	エコパワー(株)	銚子市三門町・新町・中島町付近
2009	椎柴風力発電所	5 基	1990kw	78m	82m	くろしお風力発電(有)	銚子市高田町・船木町・正明寺町

Appendix 4: Original Data Record for Visual Impact Evaluation Matrix in Spanish Method.

The original data recorded in Sarudacho, Choshi city.

	Visible wind turbine number recording	Total number of wind turbine in wind farm	Visible houses number from each wind farm	Total house number in settlement	Direction of wind farm	Distance	Population
椎柴風力発電所&銚子高田町風力発電所	4,3,1,2,0,6,3,5,0,3	6	32	263	Front	1445m,1351m,1609m,950m,1686m,1910m.Average：1492m	700
銚子ウィンドファーム	5,7,0,6,1,0,0,4,0,2	7	38	263	Diagonal	1818m,2063m,2274m,2376m,2371m,2324m,2017m.Average: 2177m	700

The original data recorded in Tokoyodacho, Choshi city.

Area	**Wind farm**	**Visible wind turbine number**	**Total number of wind turbine**	**Visible houses number from wind farm**	**Total house number**	**Direction of wind farm**	**Distance**	**Population**
North	銚子新町風力発電所	1,1,1,1,1 1,1,1	1	22	64	Front	1275m	230
	銚子ウィンドファーム	7,5,0,4,7 3,0,7	7	11	64	Front	2774m,2611m, 2523m,2221m, 2084mAverage :1745m	230
	椎柴風力発電所&銚子高田町風力発電所	2,0,3,5,1 4,0,3	6	5	64	Front	4645m,4570m, 4181m,3848m, 3664m,4419m Average:4221 m	230
South	銚子小浜風力発電所	0,1,1,0,1 0,0,0	1	4	64	Diagonal	2067m	230
	銚子屏風ヶ浦風力発電所	0,1,1,1,1 0,0,1	1	10	64	Diagonal	2112m	230
East	銚子しおさい風力発電所	2,2,1,2,1 2,2,1	2	48	64	Front	817m,617m Average:717m	230
	銚子風力発電所	9,7,9,0,8 9,0,6	9	16	64	Front	1751m,2035m, 2553m,2219m, 2471m,2652m, 1853m,2231m, 2647m.Average:2268m	230
West	八木風力発電所	4,2,0,6,6 ,4,0,2	6	31	64	Front	1469m,1190m, 730m,657m,1102m,1755m.Average:1150m	230

Appendix 5: Interview Record in Choshi City, Japan.

Residents	Date	Interview location	Q1: Biggest problem of wind turbine?	Q2:Is there any landscape impact?	Other information
男性 60 代	2010.11.6	船木町付近の農地	騒音、次は電波障害	X	No questionnaire survey of local citizen before wind farm project.
男性 50 代	2010.12.5	八木町	夜ちょっとうるさい	なし	X
女性 70 代	2010.12.5	八木町	離れてるから、関係ない	なし	X
男性 60 代	2010.12.5	小浜町	いいえ、離れてるから	なし	X
男性 50 代	2010.12.9	親田町	夜しっとり、風が強い時、仕方がない。	なし	小浜町で地元住民に対する説明会が行った、借りる形で土地を使用する。住民の反対がなし。事業が補助金あり。(NEDOから)

Appendix 6: Questionnaire Sheet in Kuzumakicho, Japan.

「葛巻町における再生可能エネルギーの促進要因とその持続可能性に対する役割に関する調査票」

研究テーマ：農村地域の再生可能エネルギー基本計画に関する研究

目的：研究の一環の先進事例研究として、葛巻町における再生可能エネルギーの促進要因、地域持続可能性に対する再生可能エネルギーの役割の課題を明らかにすることを目的としています。

＊本調査は葛巻町農林エネルギー課の職員、森林組合の役職員を対象として行う調査です。部局等組織を代表する立場としてではなく、役職員個人として記入いただくようお願い致します。
＊全ての個人情報は機密情報として扱い、いかなる組織にも公開いたしません、また、この結果は統計的に処理され、個人情報及び調査結果を公開、流出することは一切ございません。

［１］葛巻町における再生可能エネルギーの促進要因

問１、葛巻町において、今まで地元の再生可能エネルギーが発展してきた重要な要因として考えられるものを選んでください。(1–30 の中からいくつでも、当てはまる番号に○をつけてください。)

（環境面）

1. 豊富な再生可能エネルギー資源 2. 町の位置 3. 地形 4. 気候

（行政面）

5. 自治体の積極的な理念 6. 首長の積極的なイニシアティブ
7. キーパーソンの存在 8. 担当部署と関連部署の協力
9. 自治体計画への位置付け 10. 実行性の高いエネルギー戦略（計画）の策定
11. 新エネルギービジョンの策定 12. 新エネルギー宣言の策定
13. 実行性の高い計画の施策と推進

（社会面）

14. 事業主体の理解と協力 15. 住民の理解と協力
16. 大学、専門家などの協力 17. 設備提供者、会社の協力
18. 人材の確保 19. 地域の資源潜在量の把握
20. 地域内の適地の把握 21. 導入量、プロジェクト規模の把握

（経済面）

22. 予算、財源の確保 23. 国、県の助成、補助金など
24. 固定価格買取制度による売電 25. 効果の経済性の確保
26. 管理、メインテナンス費用の把握
27. 地元産業との連携（林業、畜産業など）

その他にあれば書いてください。

28. その他（ ） 29. その他（ ） 30. その他（ ）

問２、今まで葛巻町での再生可能エネルギーの発展に対する、以下の各要因を SWOT 分析の４つの項目（強み、弱み、好条件、悪条件）に評価・分類し、当てはまる項目に〇をつけてください。

SWOT 分析（SWOT analysis）とは、目標を達成するために意思決定を必要としている組織や個人の、プロジェクトなどにおける、強み（Strengths）、弱み（Weaknesses）、好条件(Opportunities)、悪条件(Threats）を評価するのに用いられる戦略計画ツールの一つ。 SWOT 分析の目的は、目標を達成するために重要な内外の要因を特定することである。

内的要因：　強み：目標達成に貢献する組織（個人）の特質。
　　　　　　弱み：目標達成の障害となる組織（個人）の特質。

外的要因：　好条件：目標達成に貢献する外部（環境、状況、条件）の特質。(機会、好機、チャンス)
　　　　　　悪条件：目標達成の障害となる外部（環境、状況、条件）の特質。(脅威、障害要因)

A		強み	弱み	好条件	悪条件
	例：人材の確保	〇			
環境面	1. 再生可能エネルギー資源量				
	2. 町の位置				
	3. 地形				
	4. 気候				
行政面	5. 自治体の理念				
	6. 首長の積極的なイニシアティブ				
	7. キーパーソンの存在				
	8. 担当部署と関連部署の協力				
	9. 自治体計画への位置付け				
	10. エネルギー戦略（計画）の策定				
	11. 「新エネルギービジョン」の策定				
	12. 新エネルギー宣言の策定				
	13. 計画の施策と推進				
社会面	14. 事業主体の理解と協力				
	15. 住民の理解と協力				
	16. 大学、専門家などの協力				
	17. 設備提供者、会社の協力				
	18. 人材の確保				
	19. 地域の資源潜在量の把握				
	20. 地域内の適地の把握				
	21. 導入量、プロジェクト規模の把握				
経済面	22. 予算、財源の確保				
	23. 国、県の助成、補助金など				
	24. 固定価格買取制度による売電				
	25. 効果の経済性の確保				
	26. 管理、メインテナンス費用の把握				
	27. 地元産業との連携（林業、畜産業など）				
その他	28. その他：（　　　　　　　　）				
	29. その他：（　　　　　　　　）				
	30. その他：（　　　　　　　　）				

［２］持続可能性に対する再生可能エネルギーの役割

以下の項目は文献や事例より取りまとめ再生可能エネルギーの持続可能性に関する項目です。葛巻町の現状に基づき、持続可能性の各項目（環境−経済−社会面）に対する、再生可能エネルギーの貢献度を評価してください。

［貢献度： +2=良い　　+1=やや良い　　0=どちらでもない　−1=やや悪い　−2=悪い］

＊お手数ですが、以下の各項目を全部評価してください。

	B	風力発電	太陽光発電、太陽光熱	バイオマス、バイオガス	小水力
	例：環境に安全	+1	+2	+1	+1
環境面	1. 温暖化防止				
	2. 環境に安全				
	3. 大気質の向上				
	4. 水質の向上				
	5. 生物多様性				
	6. 景観保全				
	7. 騒音				
	7. 廃物の再利用				
	8. その他（　　　　　　　）				
社会面	9. 農林業との連携の向上				
	10. 地域第三セクターの活性化				
	11. 森林管理、間伐材管理の向上				
	12. 施設の管理しやすさ				
	13. 地域基盤、公共施設等の整備				
	14. 土地利用				
	15. 交通（燃料面）				
	16.　エネルギー地産地消（冷暖房、給湯の提供など）				
	17. エネルギーの自立				
	18. 防災機能				
	19. 雇用創出				
	20. 健康機会				
	21. 住民参加				
	22. 環境教育				
	23. その他（　　　　　　　）				
経済面	24. 設備投資				
	25. メインテナンス費用				
	26. ローカルビジネスの促進				
	27. 地元企業の振興				
	28. 観光事業の促進				
	29. 売電事業の促進				
	30. 住民収入を増加（地代など）				
	31. その他（　　　　　　　）				

［3］質問

問１、［1］の問１で〇をつけたものの中から、最も重要なものから順位をつけてください。また、その理由も合わせてお書き下さい。

1）促進要因　第一位：(　　　　　　)番
理由：＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
2）促進要因　第二位：(　　　　　　)番
理由：＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
3）促進要因　第三位：(　　　　　　)番
理由：＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿

問２、今後まちの再生可能エネルギー事業の発展への障害となる要因は何だと思いますか。ご自由にお書きください。

＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿

問３、左の欄の表のBの中から、最も重要なものから順位をつけてください。
また、その理由も合わせてお書き下さい。

1）重要な役割　第一位：(　　　　　　)番
理由：＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
2）重要な役割　第二位：(　　　　　　)番
理由：＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
3）重要な役割　第三位：(　　　　　　)番
理由：＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿

問４、葛巻町で再生可能エネルギー施設が建設された後、町で著しく改善されたところは何だと思いますか。ご自由にお書きください。

＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿
＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿

以上で調査は終わりです。ご協力ありがとうございました。

Appendix 7: Questionnaire Sheet in Chongming Island, China.

关 于 崇 明 岛 可 再 生 能 源 发 展 的 调 查

研究课题：【关于农村地区可再生能源的空间规划研究】

调查目的：作为上述研究课题的一部分，此次调查属于其中的先进案例研究部分。目的是为了明确农村地区可再生能源发展的促进因素，以及可再生能源对当地可持续发展的作用。

前 言

*此次的调查对象为崇明岛县政府的能源相关部门职员，专家以及了解崇明岛可再生能源发展历程，规划的高校专家等。请您根据您的个人看法进行回答，尽量避免部门或官方立场的回答。

*此次调查结果仅用于学术研究，绝不用于其他目的。并且全部数据将进行统计处理，严格保密，不会泄露任何相关部门以及个人信息。

【1】崇明岛可再生能源发展的促进因素

问题 1. 对于目前可再生能源在崇明岛的成功发展，请您勾选使其成功发展的主要促进因素。（可多选，请画圈〇勾选 1-28 中选择对应编号）

(环境因素）

1.当地丰富的可再生能源资源　　2.地理区位优势

3.地形优势（平缓等）　　4.气候

(行政方面）

5. 当地政府的先进理念　　6.领导的积极态度

7.关键人物（如县长等）　　8.相关部门的支持与合作

9.当地其他规划的辅助　　10. 可行性高的能源战略和规划的制定

11. 专项能源规划的制定　　12.对规划的高效及准确的实施

(社会方面）

13.项目方的支持与合作　　14.当地住民的理解与支持

15.高校专家的支持　　16. 可再生能源设备提供方、公司等的支持

17.专业人才的确保　　18. 对岛内可再生能源资源量的准确把握

19. 在崇明岛内准确的选址　　20. 对项目规模大小的准确把握

(经济方面)

21.预算，投资等资金充足　　22.国家对于可再生能源项目的补贴

23. 电力贩卖的支持　　24.未来收益的把握

25.管理，运营费用的把握　　26.结合当地产业（生态旅游，农业等）

请补充其他方面

27.其他（　　　　）　　28.其他（　　　　）

问题 2. 对于目前可再生能源在崇明岛的发展，请评价下面A栏中的各项要素后，将其分类至以下四个大项中：“S-优势，W-弱势，O-机会，T-威胁”。请在对应的大项中打钩，如例所示。

补注：SWOT 分析是把组织内外环境所形成的优势（Strengths），劣势（Weaknesses），机会（Opportunities），风险（Threats）四个方面的情况，结合起来进行分析，以寻找制定适合组织实际情况的经营战略和策略的方法。 其目的是为了找出那些重要的内因和外因以达成某个目标。

内部因素：优势：为达成目标所拥有的优势。

劣势：达成目标的劣势。

外部因素：机会：达成目标的外部机会，状况，条件等。

风险：达成目标的外部风险，状况，条件等。

A		Strength优势	Weakness劣势	Opportunity机会	Threat风险
	例：专业人才	□			
境	1.当地可再生能源资源				
	2.地理区位				
	3.地形				
	4.气候				
政	5.当地政府的理念				
	6.领导的态度				
	7.关键人物（如县长）				
	8.相关部门的支持与合作				
	9.当地其他规划的辅助				
	10.可行性高的能源战略和规划				
	11.专项能源规划的制定				
	12.对规划的高效及准确的实施				
	13.项目方的支持与合作				
	14.当地住民的理解与支持				
	15.高校专家的支持				
	16.设备提供方，公司的支持				
	17.专业人才				
	18.对岛内可再生能源资源量的准确把握				
	19.在崇明岛内准确的选址				
	20.对项目规模大小的准确把握				
	21.预算，投资等资金充足				
	22.国家对于可再生能源项目的补贴				
	23.电力贩卖的支持				
	24.未来收益的把握				
	25.管理，运营费用的把握				
	26.结合当地产业(生态旅游，农业等)				
	27.其他：( )				
	28.其他：( )				

【2】可再生能源项目对崇明岛可持续发展的作用

下表的纵轴中的各个小项是从文献和事例中总结出的可再生能源对于可持续发展的作用。请基于崇明岛目前可再生能源发展的现状，客观地评价“可再生能源项目”对当地“可持续发展各方面”的作用大小。

[评分标准：+2有很大推进作用；+1 有一定推进作用；0 没有影响；-1分有一定副作用；-2 有很大副作用]

*注意：请耐心完成对于每个小项的评价

	可持续发展小项 B	风力发电	太阳能发电 太阳能供热	生物质能（沼气）	小型水力发电
	例：保护生物多样性	-1	+2	+1	-1
境	1.减弱温室效应				
	2.提高能源安全				
	3.保护大气				
	4.保护水源，水质				
	5.保护生物多样性				
	6.保护当地原生态景观				
	7.废物再利用（如秸秆）				
	8.其他（ ）				
会	9.加强与农林业的合作				
	10.促进第三产业发展				
	11.促进森林和合法采伐管理				
	12.设施易于管理				
	13.加强当地基础公共设施建设				
	14.土地使用				
	15.交通（燃料提供等）				
	16.能源自给自足				
	17.能源自立				
	18.增强防灾功能				
	19.提供就职机会				
	20.增进居民健康				
	21.促进居民参与				
	22.增加环境方面的教育机会				
	23.其他（ ）				
济	24.设备投资				
	25.运营管理费用				
	26.促进当地产业发展				
	27.振兴当地企业				
	28.促进观光业				
	29.促进电力贩卖				
	30.增加当地居民收入				
	31.其他（ ）				

【3】设问

问题 1. 请在“【1】-问题 1”里已经圈出的项目中选择，选出您认为其中最重要的 3 个因素，并进行排位。同时写下这样排位的理由。

1）促进因素 第一位 ：（ ）号

理由：____

2）促进因素 第二位: （ ）号

理由：____

3）促进因素 第三位: （ ） 号

理由：____

问题 2. 您认为有哪些因素会阻碍将来可再生能源在崇明岛的发展。请自由地写下您的意见。

____

____

____

问题 3. 请从左侧表格中的 B 栏里选出您认为其中最重要的 3 个项目，并进行排位。同时写下这样排位的理由。

1）对可持续发展的作用 第一位：（ ）号

理由：____

2）对可持续发展的作用 第二位：（ ）号

理由：____

3）对可持续发展的作用 第三位：（ ）号

理由：____

问题 4. 崇明岛的可再生能源项目建成之后，您认为当地产生的最显著的改变是什么。请自由地写下您的意见。

____

____

____

Appendix 8: Current RE facilities in Fukushima, Japan.

福島メガソーラー

1. 既存地メガソーラー

メガソーラー：合計 13 か所						
所在地	施設名	設備容量	単位	年度	備考	経緯度
泉崎村	エネルギーパーク泉崎	2 最大 10mw	MW	2013.9	ゴルフ場跡地を利用 森トラスト株式会社	140° 14'35.92″E. 37° 11'5.18″N
泉崎村	岩通泉崎メガソーラー発電所	2	MW	2013.10	工場の遊休地 34,500m^2	140° 19'52.09″E. 37° 8'14.55″N
相馬市	相馬太陽光発電所	1.998	mw	2013.10	58,000m^2	140° 56'9.38″E. 37° 49'55.03″N
矢吹町	レンゴー福島矢吹工場	1.535	mw	2010.5		140° 21'1.81″E. 37° 11'46.54″N
伊達市	伊達メガソーラー	1.59	MW	2011.6		140° 29'33.15″E. 37° 49'32.96″N
郡山市	郡山工場太陽光発電所	1.5	mw	2013.9	京セラケミカル株式会社 24,000m2	140° 17'55.80″E. 37° 26'51.79″N
泉崎村	Ｎツアーソーラープラントいずみざき発電所	1.238	mw	2013.9	1.8ha	140° 16'51.86″E. 37° 10'21.06″N
白河市	エルナーエナジー白河太陽光発電所	1.99	mw	2013.10	エルナーエナジー株式会社東北白河工場	140° 10'14.90″E. 37° 8'10.88″N
白河市	福島県白河市プロジェクト	1.2	mw	2013.5	40,000 ㎡	140° 18'3.14″E. 37° 2'55.60″N
いわき市	いわきユアサ太陽光発電所	1	mw	2013.6	株式会社いわきユアサ	140° 50'21.32″E. 37° 4'39.77″N
本宮市	わんだメガソーラー発電所	1.5	MW	2013.9	23,000 ㎡ 矢田工業株式会社	140° 26'53.18″E. 37° 31'42.31″N
三春町	三春物流センター発電所	1.5	MW	2013.3	東日運送	140° 36'29.10″E. 37° 22'15.37″N
須賀川市	奥地建産（株）福島工場発電所	1.6	MW	2013.5		140° 27'41.96″E. 37° 15'19.04″N

参考：森トラスト株式会社、2012、環境省「平成 24 年度地球温暖化対策技術開発・実証研究事業」における「太陽光をエネルギー源とした災害時大規模ビル電源供給に関する実証研究」の採択について。
http://www.mori-trust.co.jp/pressrelease/2012/20120912.pdf (13.11.26)

環境ビジネスオンライン、2013 年 10 月 2 日、岩崎通信機、福島県の遊休地にメガソーラー 監視装置等の製品開発に活用。
http://www.kankyo-business.jp/news/005871.php (13.11.26)

相馬太陽光発電所で発電事業を開始～震災復興モデル事業～（フジタ）
http://www.fujita.co.jp/information/news/001645.html (13.11.26)
Electrical Japan.日本全国の太陽光発電所一覧地図
http://agora.ex.nii.ac.jp/earthquake/201103-eastjapan/energy/electrical-japan/type/8.html.ja (13.12.18)
矢田工業株式会社 HP. 2013.6.6 再生可能エネルギー事業への進出について
http://www.yada-k.co.jp/topic_information/post_8.html (13.12.18)
太陽光発電ニュース、2013. 3.28. 東日運送が田村に太陽光発電 出力 750kW 2 基稼働
http://pvn24.com/20130328-3117.html (13.12.18)
Google earth での判読。

2. 建設予定地

メガソーラー建設予定地						
所在地	施設名	設備容量	単位	年度	備考	経緯度
いわき市	小名浜工場発電所	12	MW	2014.8	15ha	140° 53'33.69"E. 36° 56'38.22"N
いわき市	小名浜工場発電所	6	MW	2014.8	9ha 東北電力に売電	140° 53'33.69"E. 36° 56'38.22"N
須賀川市、玉川村	福島空港	12	MW	2014.3	2ha	140° 26'5.50"E. 37° 13'50.39"N
南相馬市	南相馬市と東芝大規模太陽光発電所	100	MW	2014	市内総計 150ha. 津波被害の沿岸部に設置：海老地区、真野地区等。	141° 0'25.48"E. 37° 41'48.01"N
西郷村	クラウド 80 メガソーラーPJ 第 1 期	最大 80mw	Mw	2013.9 から	東北復興再生エネルギー株式会社 7,590,000 ㎡	140° 7'40.44"E. 37° 7'0.66"N
西郷村	クラウド 80 メガソーラーPJ 第 2 期	最大 80mw	Mw	2013.9 から	1,320,000 ㎡	140° 10'0.51"E. 37° 9'56.58"N
白河市	クラウド 80 メガソーラーPJ 第 3 期	最大 80MW	Mw	2013.9 から	1,419,000 ㎡	140° 13'33.63"E. 37° 8'10.27"N
川内村	川内村太陽光発電所	6	MW	2014.3	9.3ha	140° 46'6.03"E. 37° 22'7.24"N
飯舘村	いいたてまでいな太陽光発電所	10	MW	2016.4	14ha 居住制限区域・飯樋地区。東北電力に売電	140° 40'39.81"E. 37° 40'2.94"N
西郷村	那須白河メガソーラー（仮）	2	MW	2014	ゴルフ隣接未利用地。23,200 ㎡	140° 9'19.45"E. 37° 8'54.28"N
須賀川市	LIXIL 須賀川 SOLAR POWER（仮称）	6.35	MW	2014	工場未活用地。約 98,000 ㎡。東北電力に売電。	140° 23'8.57"E. 37° 15'10.63"N
矢吹町	環境発電（株）メ	2	MW	2014.4	ゴルフ場アローレイ	140° 23'3.82"E.

	ガソーラー施設				クカンツリー倶楽部練習場跡地 2.5ha。東北電力に売電	37° 10'45.50"N

参考：三菱商事 HP、2013、福島県いわき市小名浜でメガソーラープロジェクトを推進 。
http://www.mitsubishicorp.com/jp/ja/pr/archive/2013/html/0000018334.html (13.11.26)
福島県 HP。2013.9.6.　福島空港メガソーラー事業
http://wwwcms.pref.fukushima.jp/download/1/130906briefingpaper01.pdf　(2013.12.18)
東芝 HP、2012 年 06 月 21 日、南相馬市と大規模太陽光発電所・スマートコミュニティ導入に関する協定書を締結
http://www.toshiba.co.jp/about/press/2012_06/pr_j2001.htm (13.11.26)
東北復興再生エネルギー株式会社 HP、2013。
http://www.trre.jp/ (13.11.26)
太陽光発電ニュース、2013.3.4.　川内村に太陽光発電所来春完成目指す。
http://pvn24.com/20130304-2927.html (13.12.18)
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3. 候補地（福島県 HP）
Google map. Kml に参照。

【福島県】メガソーラー候補地一覧表（平成２５年１０月３１日現在）.pdf
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福島風力発電

Location	Name	Year	Capacity	Turbines	Use	Longtitude
福島天栄村	羽鳥平和郷風力発電所	1995	225	2	sell	140° 2'48.5"E, 37° 15'27.5"N
福島天栄村	同上	1995	225	2	sell	140° 2'51.7"E, 37° 15'26.1"N
福島猪苗代町	中山峠風力発電	1999	250	1	road heat	140° 11'33.6"E, 37° 29'3.0"N
福島天栄村	天栄村	2000	750	4	sell	139° 57' 59.1"E, 37° 16'16.0"N
福島天栄村	同上	2000	750	4	sell	139° 58'2.1"E, 37° 16'9.0" N
福島天栄村	同上	2000	750	4	selll	139° 58'2.1"E, 37° 16'3.0" N
福島天栄村	同上	2000	750	4	sell	139° 58'6.1"E, 37° 15'43.0" N
福島郡山市	日本大学工学部郡山キャンパス	2003	40	1	campus use	140° 22'42.0"E, 37° 22'39.0" N
福島いわき市	いわき市フラワーセンター	2004	40	1	facility use	140° 54'12.0"E, 37° 5'22.0" N
福島いわき市	いわき市鬼ケ城風力発電	2006	100	1	facility use	140° 43'55.0"E, 37° 16'20.0" N
福島郡山市	グリーンパワー郡山布引	2006	2000	33	sell	140° 3'43.9"E, 37° 19'39.7"N
福島郡山市	同上	2006	2000	33	sell	140° 3'49.3"E, 37° 19'43.6"N
福島郡山市	同上	2006	2000	33	sell	140° 3'24.2"E, 37° 19'44.0"N
福島郡山市	同上	2006	2000	33	sell	140° 3'28.5"E, 37° 19'47.5"N
福島郡山市	同上	2006	2000	33	sell	140° 3'32.8"E, 37° 19'51.1"N
福島郡山市	同上	2006	2000	33	sell	140° 3'37.5"E, 37° 19'54.9"N
福島郡山市	同上	2006	2000	33	sell	140° 3'42.0"E, 37° 19'58.6"N
福島郡山市	同上	2006	2000	33	sell	140° 3'46.6"E, 37° 20'2.6"N
福島郡山市	同上	2006	2000	33	sell	140° 3'48.6"E, 37° 20'10.4"N
福島郡山市	同上	2006	2000	33	sell	140° 3'44.9"E, 37° 20'15.6"N
福島郡山市	同上	2006	2000	33	sell	140° 3'27.7"E, 37° 20'13.0"N

福島郡山市	同上	2006	2000	33	sell	140° 3’22.9″E, 37° 20’8.9″N
福島郡山市	同上	2006	2000	33	sell	140° 3’17.7″E, 37° 20’4.6″N
福島郡山市	同上	2006	2000	33	sell	140° 3’12.1″E, 37° 20’0.1″N
福島郡山市	同上	2006	2000	33	sell	140° 3’7.3″E, 37° 19’56.0″N
福島郡山市	同上	2006	2000	33	sell	140° 3’2.4″E, 37° 19’51.8″N
福島郡山市	同上	2006	2000	33	sell	140° 2’54.1″E, 37° 19’53.9″N
福島郡山市	同上	2006	2000	33	sell	140° 2’36.5″E, 37° 19’58.3″N
福島郡山市	同上	2006	2000	33	sell	140° 2’40.5″E, 37° 20’5.0″N
福島郡山市	同上	2006	2000	33	sell	140° 2’45.0″E, 37° 20’9.0″N
福島郡山市	同上	2006	2000	33	sell	140° 2’50.4″E, 37° 20’13.5″N
福島郡山市	同上	2006	2000	33	sell	140° 2’55.0″E, 37° 20’17.2″N
福島郡山市	同上	2006	2000	33	sell	140° 3’5.1″E, 37° 20’24.4″N
福島郡山市	同上	2006	2000	33	sell	140° 3’10.7″E, 37° 20’31.5″N
福島郡山市	同上	2006	2000	33	sell	140° 2’56.5″E, 37° 20’33.9″N
福島郡山市	同上	2006	2000	33	sell	140° 2’24.0″E, 37° 20’6.0″N
福島郡山市	同上	2006	2000	33	sell	140° 2’13.8″E, 37° 20’13.0″N
福島郡山市	同上	2006	2000	33	sell	140° 2’18.7″E, 37° 20’16.8″N
福島郡山市	同上	2006	2000	33	sell	140° 2’22.2″E, 37° 20’21.1″N
福島郡山市	同上	2006	2000	33	sell	140° 2’26.4″E, 37° 20’28.0″N
福島郡山市	同上	2006	2000	33	sell	140° 2’30.6″E, 37° 20’32.5″N
福島郡山市	同上	2006	2000	33	sell	140° 2’35.5″E, 37° 20’37.9″N
福島郡山市	同上	2006	2000	33	sell	140° 2’32.3″E, 37° 20’44.6″N

福島田村市川内村	滝根小白井ウインドファーム	2010	2000	23	sell	140° 42'53.8"E, 37° 20'16.7"N
福島田村市川内村	同上	2010	2000	23	sell	140° 42'58.7"E, 37° 20'4.5"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'5.1"E, 37° 19'56.2"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'9.2"E, 37° 19'50.9"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'10.8"E, 37° 19'44.3"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'11.2"E, 37° 19'37.2"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'4.5"E, 37° 19'18.7"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'2.7"E, 37° 19'12.9"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'1.6"E, 37° 19'6.7"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'19.8"E, 37° 19'14.7"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'32.1"E, 37° 19'6.6"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'19.8"E, 37° 18'59.5"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'11.9"E, 37° 18'50.9"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'32.7"E, 37° 18'58.5"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'29.8"E, 37° 18'51.4"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'12.4"E, 37° 18'44.0"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'16.7"E, 37° 18'36.6"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'29.5"E, 37° 18'43.7"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'13.1"E, 37° 18'30.1"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'31.9"E, 37° 18'31.0"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'46.4"E, 37° 18'40.5"N
福島田村市川内村	同上	2010	2000	23	sell	140° 43'48.7"E, 37° 18'25.7"N

福島田村市川内村	同上	2010	2000	23	sell	140° 42’54.3″E, 37° 20’10.3″N
福島田村市川内村	桧山高原風力発電所	2011	2000	14	sell	140° 43’5.0″E, 37° 23’51.9″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’3.0″E, 37° 24’0.2″N
福島田村市川内村	同上	2011	2000	14	sell	140° 42’60.0″E, 37° 24’5.6″N
福島田村市川内村	同上	2011	2000	14	sell	140° 42’51.7″E, 37° 24’10.4″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’25.6″E, 37° 24’0.2″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’32.1″E, 37° 24’6.2″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’22.4″E, 37° 24’11.7″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’17.8″E, 37° 24’16.2″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’16.4″E, 37° 24’24.1″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’31.5″E, 37° 24’26.7″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’40.9″E, 37° 24’22.8″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’38.7″E, 37° 24’15.9″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’53.3″E, 37° 24’12.2″N
福島田村市川内村	同上	2011	2000	14	sell	140° 43’56.9″E, 37° 24’17.5″N

参考；Google earth での判読

NEDO, 風況マップ

福島大規模水力発電・小水力発電

a. 国土交通省、国土数値地図、発電所のGISデータ内有る発電所（共14カ所）:

大規模水力発電･中水力発電					
所在地	施設名	設備容量	単位	年度	経緯度
桧枝岐村	奥只見発電所	560	MW	1960	139° 14 '58″E. 37° 09 '13″N
只見町	大鳥発電所	182	MW	1963	139° 12'47.02″E. 37° 12'57.13″N
只見町	田子倉発電所	380	MW	1959	139° 17 '13″E. 37° 18 '38″N
只見町	只見発電所	65	MW	1989	139° 18'6.41″E. 37° 20'7.17″N
金山町	滝発電所	92	MW	1961	139° 23'2.37″E. 37° 23'13.05″N
金山町	本名発電所	78	MW	1954	139° 29'36.25″E. 37° 26'29.51″N
金山町	上田発電所	63.9	MW	1954	139° 32'14.43″E. 37° 28'59.64″N
三島町	宮下発電所	94	MW	1946	139° 37'45.19″E. 37° 27'46.96″N
柳津町	柳津発電所	75	MW	1953	139° 42'23.06″E. 37° 31'9.05″N
西会津町	上野尻発電所	52	MW	1958	139° 37'54.36″E. 37° 37'57.18″N
会津坂下町	片門発電所	57	MW	1953	139° 45'46.05″E. 37° 33'51.52″N
喜多方市	新郷発電所	51.6	MW	1939	139° 44'11.99″E. 37° 36'40.23″N
会津若松市	猪苗代第一発電所	62.4	MW	1914	140° 0'7.03″E. 37° 32'37.94″N
猪苗代町	秋元発電所	107.5	MW	1940	140° 7'55.10″E. 37° 36'29.65″N

参考：国土交通省、国土数値地図、発電所。

Electrical Japan.日本全国の水力発電所一覧地図

http://agora.ex.nii.ac.jp/earthquake/201103-eastjapan/energy/electrical-japan/type/4.html.ja (13.12.13)

Google earthでの位置判読。(13.12.13)

b. 日本全国の水力発電所一覧地図と東北電力HPとGoogle earthでの判読から得られた発電所：

所在地	施設名	設備容量	単位	年度	経緯度
喜多方市	山郷発電所 山郷第二発電所	23 22.9	MW	1943	139° 41'11.53″E. 37° 36'24.85″N
桧枝岐村	大津岐発電所	38	MW	1968	139° 17'55.72″E. 37° 2'52.66″N
只見町	黒谷発電所	19.6	MW	1994	139° 23'55.28″E. 37° 11'38.20″N
金山町	伊南川発電所	19.4	MW	1938	139° 27'44.33″E. 37° 23'49.90″N
磐梯町	猪苗代第四発電所	37.1	MW	1926	139° 55'45.37″E. 37° 34'46.00″N
会津若松市	日橋川発電所	10.6	MW	1912	139° 57'3.89″E. 37° 33'56.61″N
会津若松市	猪苗代第二発電所	37.5	MW	1926	139° 59'3.06″E. 37° 33'8.66″N
会津若松市	猪苗代第三発電所	23.2	MW	1926	139° 57'42.63″E. 37° 33'22.60″N
下郷村	大川発電所	21	MW	1986	139° 54'36.48″E. 37° 20'51.50″N
北塩原村	小野川発電所	34.2	MW	1937	140° 6'35.05″E. 37° 39'37.72″N
猪苗代町	沼ノ倉発電所	18.9	MW	1946	140° 7'25.00″E. 37° 34'45.62″N

福島市	大笹生発電所	11.4	MW	1991	140° 22’39.17″E. 37° 47’44.82″N
福島市	蓬莱発電所	38.5	MW	1938	140° 29’45.06″E. 37° 41’50.43″N
楢葉町	木戸川第二発電所	14.3	MW	1936	140° 56’34.50″E. 140° 56’34.50″E
会津美里町	新宮川ダム発電所	1.1	MW	2003	139° 46’51.83″E. 37° 21’51.05″N
喜多方市	日中発電所	1.7	MW	1995	139° 54’29.33″E. 37° 45’12.48″N
会津若松市	金川発電所	6.5	MW	1912	139° 55’28.50″E. 37° 34’43.01″N
会津若松市	戸の口堰第一発電所	2.08	MW	1941	139° 58’46.95″E. 37° 31’11.27″N
会津若松市	戸の口堰第三発電所	1.4	MW	1941	139° 57’23.75″E. 37° 30’45.20″N
会津美里町	本郷発電所	2.1	MW	1957	139° 54’14.82″E. 37° 26’48.02″N
会津若松市	小谷発電所	3.3	MW	1990	139° 55’44.88″E. 37° 23’3.65″N
下郷村	鶴沼川発電所	7.1	MW	1931	139° 54’13.03″E. 37° 18’32.44″N
下郷村	湯野上発電所	7.2	MW	1937	139° 54’2.30″E. 37° 17’52.24″N
郡山市	沼上発電所	2.1	MW	1899	140° 11’59.29″E. 37° 29’10.45″N
郡山市	竹ノ内発電所	3.7	MW	1919	140° 13’8.72″E. 37° 29’35.70″N
郡山市	丸守発電所	5.9	MW	1921	140° 16’2.60″E. 37° 28’53.66″N
郡山市	安積疏水管理用発電所	2.23	MW	2004	140° 13’21.01″E. 37° 25’29.26″N
福島市	摺上川発電所	3	MW	2004	140° 25’15.54″E. 37° 55’29.41″N
福島市	穴原発電所	1.85	MW	1912	140° 26’20.16″E. 37° 50’32.53″N
福島市	庭坂発電所	1.5	MW	2001	140° 21’10.40″E. 37° 46’22.25″N
福島市	荒川発電所	3.1	MW	1939	140° 20’53.28″E. 37° 42’19.74″N
福島市	土湯発電所	2.38	MW	1920	140° 20’5.03″E. 37° 41’49.68″N
福島市	信夫発電所	5.95	MW	1939	140° 29’47.51″E. 37° 43’1.95″N
二本松市	小瀬川発電所	1.1	MW	1921	140° 30’59.35″E. 37° 35’29.91″N
三春町	三春ダム発電所	1.05	MW	1998	140° 28’30.90″E. 37° 24’17.33″N
飯舘村	真野発電所	1.1	MW	1992	140° 49’59.90″E. 37° 43’7.28″N
南相馬市	石神発電所	8.7	MW	1944	140° 53’24.36″E. 37° 39’4.15″N
田村市	古道川発電所	2.49	MW	1940	140° 49’7.32″E. 37° 27’50.70″N
浪江町	高瀬川発電所	5.8	MW	1979	140° 51’48.45″E. 37° 27’39.48″N
川内村	木戸川第一発電所	2.57	MW	1924	140° 51’49.93″E. 37° 16’35.89″N
楢葉町	木戸川第三発電所	1.0	MW	1939	140° 57’32.99″E. 37° 16’36.83″N
いわき市	川前発電所	1.4	MW	1916	140° 41’34.75″E. 37° 14’1.73″N
いわき市	夏井川第一発電所	4	MW	1916	140° 49’31.52″E. 37° 9’45.45″N
いわき市	夏井川第二発電所	3.5	MW	1920	140° 48’3.38″E. 37° 11’22.27″N
いわき市	夏井川第三発電所	1.8	MW	1927	140° 49’52.40″E. 37° 9’0.07″N
いわき市	小玉川第一発電所	2.8	MW	1931	140° 50’6.23″E. 37° 7’36.72″N
いわき市	小玉川第二発電所	2.92	MW	1935	140° 48’25.64″E. 37° 7’44.79″N
いわき市	大利第一発電所	1.0	MW	1920	140° 47’55.32″E. 37° 4’33.77″N
古殿町	鮫川発電所	2.6	MW	1940	140° 37’17.23″E. 37° 2’14.42″N
いわき市	柿の沢発電所	4.8	MW	1955	140° 42’36.09″E. 37° 0’3.43″N
いわき市	高柴ダム発電所	1.6	MW	1985	140° 43’59.97″E. 36° 57’20.50″N

いわき市	四時川第一発電所	4	MW	1922	140° 41'5.75″E. 36° 55'57.01″N
いわき市	四時川第二発電所	1.23	MW	1927	140° 39'25.34″E. 36° 55'32.40″N
いわき市	小川発電所	2.4	MW	1922	140° 43'6.55″E. 36° 54'21.41″N
南会津町	内川発電所	0.53	MW	1927	139° 29'28.95″E. 37° 8'38.02″N
柳津町	滝谷川発電所	0.445	MW	1920	139° 41'18.32″E. 37° 25'12.77″N
会津美里町	宮川発電所	0.82	MW	1921	139° 48'3.41″E. 37° 25'29.56″N
西会津町	奥川第二発電所	0.56	MW	1921	139° 37'4.15″E. 37° 39'38.71″N
喜多方市	大平沼発電所	0.57	MW	1991	139° 50'40.26″E. 37° 45'5.42″N
会津若松市	戸の口堰第二発電所	0.85	MW	1919	139° 58'25.83″E. 37° 31'27.31″N
会津若松市	東山発電所	0.28	MW	1902	139° 57'29.08″E. 37° 28'48.87″N
会津若松市	東山ダム発電所	0.7	MW	1982	139° 58'2.50″E. 37° 27'38.07″N
西郷村	真船発電所	0.999	MW	1927	140° 4'34.84″E. 37° 10'13.61″N
福島市	滝野発電所	0.9	MW	1910	140° 25'59.73″E. 37° 53'16.32″N
二本松市	沢上発電所	0.34	MW	1908	140° 33'37.54″E. 37° 33'18.31″N
二本松市	仏台発電所	0.15	MW	1915	140° 34'14.74″E. 37° 33'0.77″N
三春町	移川発電所	0.33	MW	1926	140° 32'52.49″E. 37° 30'16.84″N
三春町	青石発電所	0.2	MW	1919	140° 33'23.53″E. 37° 29'49.88″N
須賀川市	前田川発電所	0.25	MW	1906	140° 24'17.87″E. 37° 15'0.40″N
塙町	雨谷発電所	0.52	MW	1923	140° 26'43.79″E. 36° 58'5.19″N
塙町	川上発電所	0.8	MW	1935	140° 26'51.08″E. 36° 55'39.24″N
浪江町	昼曽根発電所	0.5	MW	1913	140° 51'52.08″E. 37° 32'23.86″N
いわき市	鹿又川発電所	0.68	MW	1921	140° 45'28.27″E. 37° 12'19.22″N
いわき市	大利第二発電所	0.316	MW	1920	140° 46'40.86″E. 37° 5'27.19″N
いわき市	塩田発電所	0.56	MW	1927	140° 50'24.86″E. 37° 8'26.88″N
桧枝岐村	檜枝岐発電所	0.06	MW	1922	139° 23'25.92″E. 37° 1'38.53″N

参考：Electrical Japan.日本全国の水力発電所一覧地図
http://agora.ex.nii.ac.jp/earthquake/201103-eastjapan/energy/electrical-japan/type/4.html.ja (13.12.13)

Google earth での位置判読。(13.12.13)

東北電力 HP、主な発電所。http://www.tohoku-epco.co.jp/comp/gaiyo/gaiyo_data/hatudensyo.html (13.12.13)

水力ドットコム、www.suiryoku.com (13.12.13)

福島県の発電所　水力発電。http://www42.tok2.com/home/kaidoweb/EPC.htm (13.12.14)

福島・バイオマス

バイオマス発電						
所在地	施設名	設備容量	単位	年度	備考	経緯度
いわき市（民間）	いわき大王製紙	7,760	kW	2001.H13		140° 44' 48.03"E. 36° 56' 17.67"N
いわき市（民間）	トラスト企画リサイクルセンター遠野事業所	100	kW	2007.H19		140° 44' 46.43"E. 36° 58' 11.38"N
いわき市（民間）	日本製紙勿来工場	15,000	kW	2004.H16		140° 46' 13.23"E. 36° 53' 46.91"N
白河市（民間）	（株）白河ウッドパワーバイオマス発電所	11,500	kW	2006.H18	木材チップ利用量 116,000 t/年	140° 16' 21.36"E. 37° 11' 41.39"N
会津若松	グリーン発電会津河東発電所	5,700	kW	2010	木材チップ利用 60,000t/年	139° 57' 20.08"E. 37° 32' 51.97"N
塙町ー中止。	新設計画発電所（塙町東河内字一本木)2013 年 9 月、住民の反対により、発電所の計画を中止した。	1,2000	kW	2014	木材チップ利用 112,000t/年。100Bq/kg 以下木材を利用。	
バイオマス熱利用						
会津若松市	下水浄化工場	298	ｋｌ	2001.H13	消化ガス６万 m3	139° 53' 0.70"E. 37° 31' 21.63"N
会津坂下町	糸桜里の湯ばんげ	402	ｋｌ	2007.H19		139° 47' 57.96"E. 37° 35' 18.81"N
いわき市	田人ふれあい館(田人公民館)	201	ｋｌ	2004.H16		140° 42' 17.34"E. 36° 57' 7.28"N
いわき市	田人おふくろの宿	201	ｋｌ	2005.H17		140° 39' 41.37"E. 36° 56' 28.88"N
いわき市	東部浄化センター	217	ｋｌ	2003		140° 52' 21.86"E. 36° 56' 24.18"N
いわき市	北部浄化センター	163	ｋｌ	1974.S49		140° 56' 37.72"E. 37° 3' 48.43"N
いわき市（民間）	いわき大王製紙	27,555	ｋｌ	2001.H13		140° 44' 48.03"E. 36° 56' 17.67"N
いわき市（民間）	日本製紙勿来工場	48,140	ｋｌ	2004.H16		140° 46' 13.23"E. 36° 53' 46.91"N
南相馬	原町第一下水処理	254	ｋｌ	1976.S51	300 立米ガスホ	140° 58' 10.17"E.

市	場				ルダー	37° 38' 40.17"N
郡山市	農業総合センター	20,000	Kcal/h	2008.H20		140° 23' 15.62"E. 37° 28' 23.52"N
いわき市	いわき市役所常磐学校給食調理センター	580	kl	2006.H18		140° 49' 45.91"E. 36° 59' 50.21"N
いわき市	いわき市フラワーセンター	523	kl	2006.H18		140° 54' 14.14"E. 37° 5' 30.34"N
本宮市	アサヒビール 福島工場	3068	kl	1993.H5		140° 22' 54.72"E. 37° 28' 50.02"N
塙町	協和木材（株）	-	kl	2005.H17		140° 24' 52.41"E. 36° 58' 35.62"N
川内村	かわうちの湯	-	kl	2010.H22		140° 48' 34.20"E. 37° 20' 7.74"N
飯舘村	(社)いいたて福祉会「いいたてホーム」	24	kl	2008.H20		37° 40' 40.68"N. 37° 40' 40.68"N
バイオマス燃料製造						
北塩原村	いこいの森食用油リサイクル製作所	200	L／日	2003.H15	BDF 燃料製造	140° 0' 47.95"E. 37° 39' 31.95"N
須賀川市（民間）	㈱ひまわり	400	L／日	2004.H16	BDF 燃料製造	140° 22' 11.89"E. 37° 18' 52.83"N
いわき市（民間）	木質ペレット製造設備施設 遠野興産㈱	3	t／日	2005.H17	木質ペレット製造	140° 44' 29.23"E. 36° 58' 25.39"N
いわき市（民間）	食用油リサイクル工場	1500	L/日	2004	BDF 燃料製造	140° 56' 52.31"E. 37° 8' 24.71"N

参考：福島県、うつくしまの新エネルギーHP、福島県の新エネルギー事情、県内の新エネ施設一覧（市町村別）。
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社団法人地域環境資源センター、バイオマス利活用技術情報データベース、登録済み施設一覧（バイオディーゼル燃料）。
http://www2.jarus.or.jp/biomassdb/instinfolist03.html (13.12.17)
株式会社グリーン発電会津 HP. http://gh-aizu.co.jp/ (13.12.25)
Google earth での位置判読。

福島地熱発電所

所在地	施設名	設備容量	単位	年度	経緯度
柳津町	柳津西山地熱発電所	65,000	kW	1995	139° 41 ’38″E. 37° 26 ’24″N
磐梯朝日国立公園（地表調査で協議中）					

参考：福島県、うつくしまの新エネルギーHP、福島県の新エネルギー事情、県内の新エネ施設一覧（市町村別）。

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国土交通省、国土数値地図、発電所。Google earth での位置判読。Wikipedia 柳津西山地熱発電所。

福島温度差エネルギー・天然ガスコージェネレーション

所在地	施設名	設備容量	単位	年度	備考	経緯度
温度差エネルギー						
猪苗代町（国）	国土交通省郡山国道事務所　猪苗代湖湖水熱利用ロードヒーティング	175	kl	2000.H12		140°　1’52.38″E. 37° 30’40.49″N
天然ガスコージェネレーション						
会津若松市(県)	会津大学	400	kW	1994.H6		139° 56’17.50″E. 37° 31’27.06″N
いわき市(県)	アクアマリンふくしま	371	kW	2000.H12		140° 54’5.07″E. 36° 56’33.62″N

参考：福島県、うつくしまの新エネルギーHP、福島県の新エネルギー事情、県内の新エネ施設一覧（市町村別）。http://www.pref.fukushima.jp/chiiki-shin/shinene/enefks/02/index.html (13.10.28)

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Google earth での位置判読。

福島・火力発電所

火力						
所在地	施設名	設備容量	単位	年度	備考・主な使用燃料	経緯度
広野町	広野火力発電所	3,800	MW	1980	東京電力。石炭・重油・原油	141° 0'48.96"E. 37° 13'56.56"N
南相馬市	原町火力発電所	2,000	MW	1997	東北電力石炭・木質バイオマス	141° 1'3.21"E. 37° 39'51.15"N
新地町	新地発電所	2,000	MW	1994	東北電力・東京電力・相馬共同火力発電。石炭・木質バイオマス	140° 56'43.62"E. 37° 50'35.48"N
いわき市	勿来発電所	1,625	MW	1957	東北電力・東京電力・常磐共同火力。石炭・重油・炭化燃料・木質バイオマス	140° 48'53.33"E. 36° 54'39.77"N

参考：国土交通省、数値地図、発電所。

火力発電.com。福島県にある火力発電所一覧。http://xn--tfrr70e8ee8z1b.com/1/fukushima.html (13.12.17)

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Google earth での位置判読。(13.12.17)

福島廃物熱利用・発電

所在地	施設名	設備容量	単位	年度	備考	経緯度
廃棄物熱利用						
福島市	あぶくまクリーンセンター	165	ｋｌ	1988.S63		140° 29'29.17"E. 37° 45'47.40"N
福島市	あらかわクリーンセンター	119	ｋｌ	1977.S52		140° 25'28.06"E. 37° 45'5.90"N
郡山市	河内クリーンセンター	1,548	ｋｌ	1984.S59		140° 16'10.91"E. 37° 24'54.31"N
郡山市	富久山清掃センター	6,761	ｋｌ	1996.H8		140° 24'46.27"E. 37° 25'49.03"N
いわき市	北部清掃センター	380	ｋｌ	1980.S55		140° 55'32.14"E. 37° 4'30.53"N
いわき市	南部清掃センター	2,850	ｋｌ	2000.H12		140° 50'47.10"E. 36° 56'26.96"N
白河市	西白河地方クリーンセンター	133	ｋｌ	1995.H7		140° 13'23.78"E. 37° 5'9.61"N
白河市（民間）	住友ゴム工業白河工場	2,297	ｋｌ	1996.H8		140° 15'8.78"E. 37° 6'22.65"N
南相馬市	クリーン原町センター	106	ｋｌ	1988.S63		140° 57'50.12"E. 37° 40'9.84"N
須賀川市	衛生センター	597	ｋｌ	1990.H2		140° 22'0.27"E. 37° 19'4.89"N
廃棄物発電						
福島市	あぶくまクリーンセンター	800	kW	1988.S63		140° 29'29.17"E. 37° 45'47.40"N
郡山市	河内クリーンセンター	1,000	kW	1984.S59		140° 16'10.91"E. 37° 24'54.31"N
郡山市	富久山清掃センター	1,950	kW	1996.H8		140° 24'46.27"E. 37° 25'49.03"N
いわき市	南部清掃センター	3,500	kW	2000.H12		140° 50'47.10"E. 36° 56'26.96"N
大熊町（民間）	エヌ・イー大熊㈱	780	kW	1993.H5		141° 1'59.90"E. 37° 23'40.89"N

参考：福島県、うつくしまの新エネルギーHP、福島県の新エネルギー事情、県内の新エネ施設一覧（市町村別）。
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Google earth での判読。

Appendix 9:「第１回福島県再生可能エネルギー普及アイデアコンテスト」

応募作品（王倩娜，木村亜維子；指導教員：木下勇）

福島県における再生可能エネルギーを基盤とした持続可能なライフスタイルの提案

0. 福島県民ひとりひとりの手で実現させるアクションプランのために

福島県を「再生可能エネルギー先駆けの地」とするため、「再生可能エネルギーを基盤とした持続可能なライフスタイル」をご提案します。2040 年に福島県内の消費電力 100%を再生可能エネルギーで創出する体制を実現するためには、なによりも、福島県で暮らす住民の方、ひとりひとりの生活空間やライフスタイルから考え始める必要があるのではないかと考えました。住民ひとりひとりの手で獲得する未来は、持続可能な社会の第一歩となり、アクションプラン実現への近道であると考えます。

再生可能エネルギーは地形天候などの条件と強く関連し、資源の空間分布特性により、区域またはローカルレベルの自然、社会、法制制限などを考えた計画が必要です。特に、東日本大震災で大きく被災した福島県で避難人口の移動と帰還､放射能なども考量した再生可能エネルギーの促進対策が求められます。そこで、福島県全域を対象をとし、地域エネルギーの地産地消や持続可能な計画等の視点から､未来の再生可能エネルギーの自給自足の可能性及び地域に役立つ再生可能エネルギー基本計画立案のため、GIS を活用した「福島県における再生可能エネルギーの総合マップ(P.9)」を作成しました。この総合マップをもとに､「福島県における再生可能エネルギーシナリオマップ」をまとめ、特徴が分かれる浜通り・中通り・会津の３つのエリアごとに、再生可能エネルギーを基盤とした持続可能なライフスタイルを提案します。

1. 再生可能エネルギーシナリオマップ

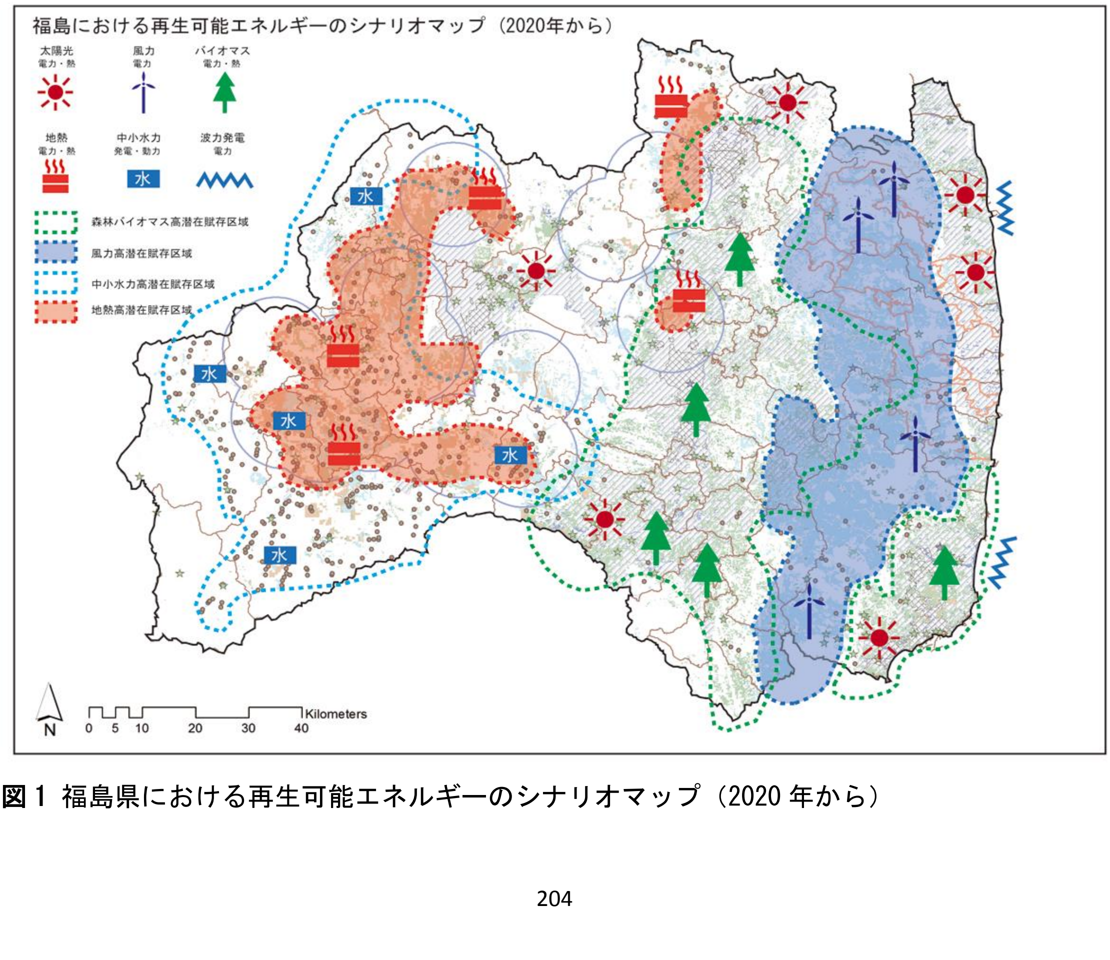

図 1 福島県における再生可能エネルギーのシナリオマップ（2020 年から）

GIS によってエネルギー資源の適地を求めた「福島県における再生可能エネルギーの総合マップ(作成手順は P.4-P.10 で説明)」より、福島県全域の再生可能エネルギーのポテンシャルが明らかになりました。地域の特徴として、浜通りは、太陽光、風力、波力、バイオマス、中通りはバイオマス、会津は地熱、中小水力の高潜在賦存区域であることがわかります（**図 1**)。それより、福島県全域において、再生可能エネルギーを基盤としたライフスタイルの構築が可能であるといえます。
「再生可能エネルギーシナリオマップ」には、再生可能エネルギーを基盤とした持続可能なライフスタイルを構築するため、土台となる再生可能エネルギーの高潜在賦存区域をエネルギーの種類ごとに示しています。

2.スマートコミュニティネットワークの構築
　今回の提案では、一極集中の大規模な発電方式ではなく、集落単位のような小規模の単位ごとにスマートコミュニティを構築し、コミュニティ内において、電力が自給自足できるような小規模分散型の仕組みを提案します（**図 2**)。「福島県における再生可能エネルギーのシナリオマップ（p.1 **図 1**)」を参考にし、各地域ごとに地域の特性にあった再生可能エネルギーを選択することができます。住民は、「半農半 X」というライフスタイルに＋α として、スマートコミュニティの発電方式を共同で運営・管理します。
　福島県を、現在電力会社が占有している送電線を開放できる特区とし、コミュニティでの余剰電力は近隣のコミュニティへ供給、さらに近隣間でも余剰となる電力に関しては、首都圏へ売電させます。
コミュニティの発電装置で発生する電力及び、熱、動力は、コミュニティ内の各家庭と、コミュニティで経営する植物工場やハウス農業、ゲストハウスなどへ供給されます。コミュニティ内のエネルギーはスマートメーターにより管理され、電力の需要と供給のバランスを効率よく制御し、住民の手で発電装置の運営・管理を行ないます。
　スマートコミュニティは、電力を含む生活に必要なものの自給自足を目指し、自立したコミュニティを構築します(**図 3**)。

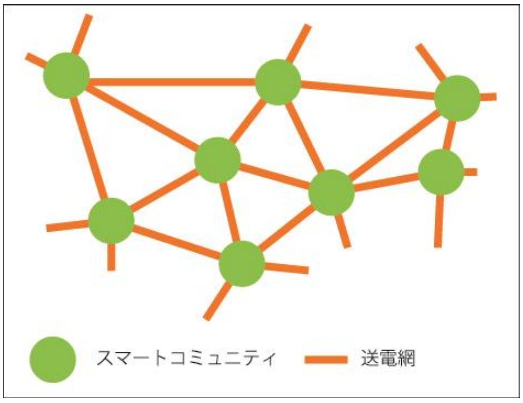

図 2　スマートネットワーク概念図

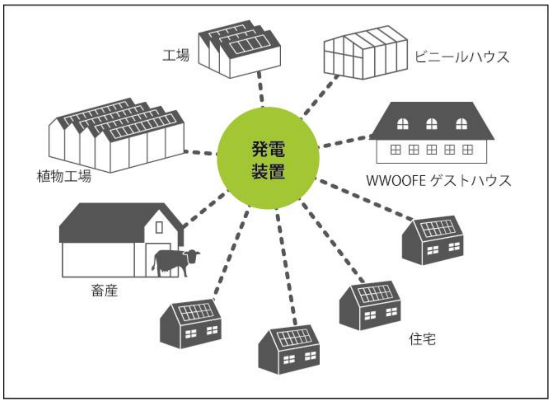

図 3　スマートコミュニティ概念図

※「半農半 X」[1]：塩見直紀氏（1965 年-）が提唱する、半自給的な農のある暮らしとやりたい仕事を両立させるライフスタイルのコンセプト。

県外から人をよぶ取り組み「WWOOFE(ウーフィ)」の提案
地域の外から人びとを呼び込む仕掛けとして、現在世界に広がるファームステイの取り組み「WWOOF(World Wide Opportunities on Organic Farms)」ウーフを参考にし､「WWOOFE(World Wide

Opportunities on Organic Farms and Energy)」ウーフィという新たな取り組みを提案します。WWOOFE では、農場での労働体験だけではなく、発電装置での労働体験ができ、スマートコミュニティにおいて持続可能なライフスタイルを体験することができます。再生可能エネルギーや、持続可能なライフスタイルが注目を浴びる現在、福島県は、日本中、世界中からスマートコミュニティネットワークのコンセプトに共感した人びとが集まる拠点となることが期待されます。また、コンセプトに共感し、集まってくる人びとにより、新たなコミュニティが生まれ、WWOOFE をきっかけに、参加者である WWOOFEer が新住民となる可能性も考えられます。スマートコミュニティネットワークに WWOOFE を組み込むことで、持続可能なコミュニティ形成のみならず、WWOOFEer を居住者へと導き、人口増加へとつなげることができます。

※「WWOOF(World Wide Opportunities on Organic Farms)」(世界に広がる有機農場での機会)「食事・宿泊場所」と「労働力」を交換する仕組み。お金のやりとりは一切ないファームステイ。「食事・宿泊場所」を提供する側をホスト(HOST)とよび、「労働力」を提供する側をウーファー(WWOOFer)とよぶ。

3. 再生可能エネルギーを基盤とした持続可能なコミュニティの仕組み

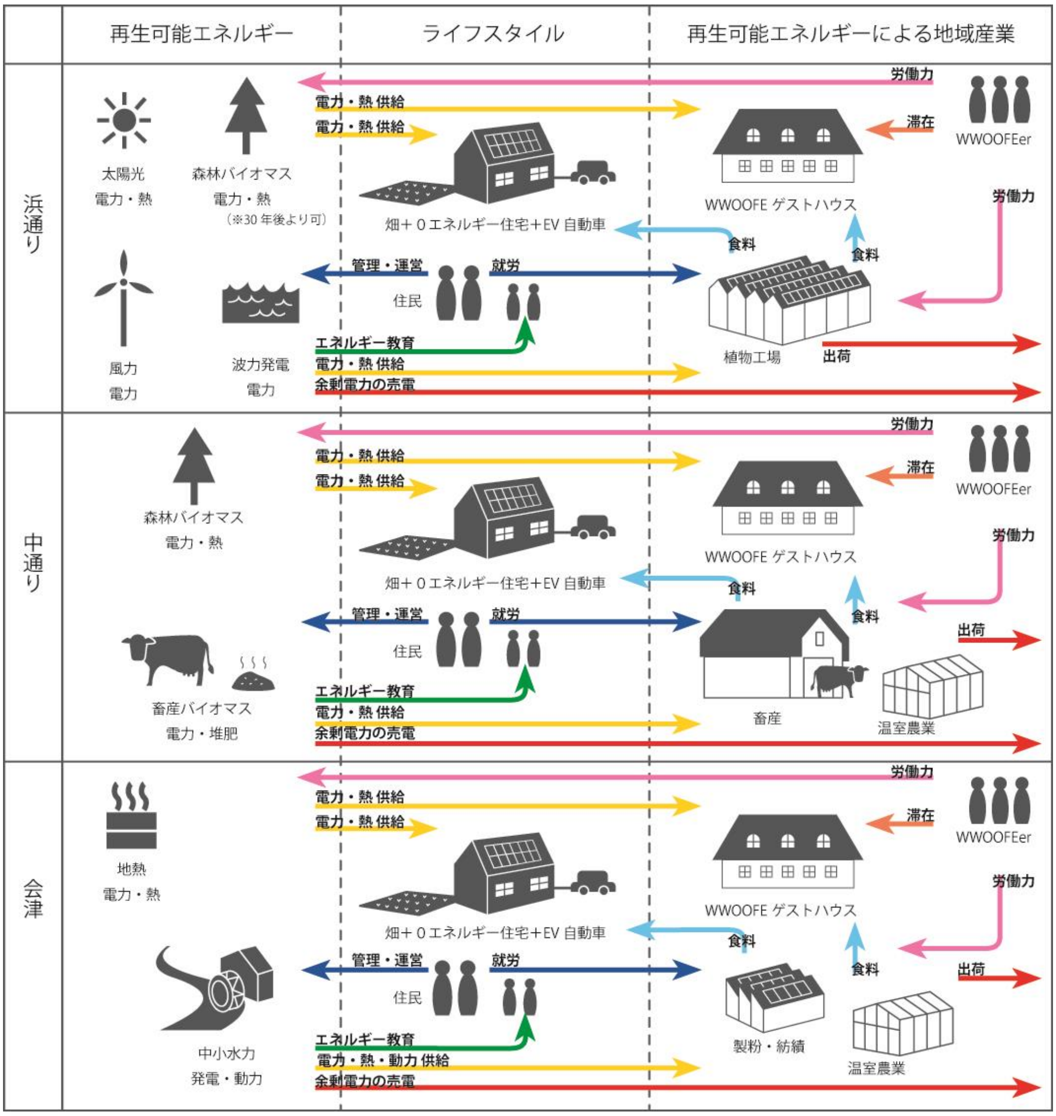

図 4　地域別再生可能エネルギーを基盤とした持続可能なコミュニティの仕組み図

浜通り、中通り、会津の地域別に、再生可能エネルギーを基盤とした持続可能なコミュニティの仕組みを提案します。**図 4** にある再生可能エネルギーを基盤とした地域産業の他にも、今既にある地域産業や地域の文化、歴史資産などを組み合わせることで、福島県全域の各コミュニティがより多様で豊かなものとなると考えられます。小規模分散型のコミュニティは、住民一人一人の意思と力により運営され、コミュニティネットワークにより足りないものは、コミュニティ間で補完しあえるという、住民主体で自立的な社会が構築されます。以上の持続可能なライフスタイルと、コミュニティネットワークは、人口減少社会に直面した日本において、未来の希望として先進的事例となると考えられます。

「福島県における再生可能エネルギーの総合マップ」作成

1. 目的

福島における再生可能エネルギーの未来像とその自給自足の可能性を探ることを目的とする。

2. 方法

再生可能エネルギーで自給自足の可能性と未来像を明らかにするため、下記の手順を提案する。

1) エネルギー消費量予測：一次エネルギー消費量
2) 再生可能エネルギーのポテンシャルマップ作成：潜在賦存量と利用可能量
3) 再生可能エネルギーの自給自足マップ作成
4) 総合マップ作成
5) 意思決定支援：再生可能エネルギーの空間計画、住宅計画などの参考とし

各手順は下記の「2.1」-「2.5」で詳しく説明する。

2.1 エネルギー消費量：一次エネルギー消費量

元 GIS 人口データは 2010 年のデータであり、2011 年の東日本大震災により避難人口の移動などがあったため、GIS で人口補正を行った。人口補正及び一次エネルギー消費量マップの作成手順は**表 1** に参照。

表 1　一次エネルギー消費量マップの作成手順

手順	詳細	参考
1. GIS 人口データ	平成 22 年国勢調査（小地域）。福島県、人口総数及び世帯総数。	[2]
2. 避難人口補正 (2011 年 9 月 22 日時点)	避難区域から県内への避難：7 万 817 人 避難区域から県外への避難：2 万 9693 人 避難区域以外から県内への自主的避難：2 万 3551 人 避難区域以外から県外への自主的避難：2 万 6776 人	[3-5]
3. 避難指示区域内人口補正	経産省、避難指示区域の見直し後の各市町村の概念図	[6]
4. 避難指示区域内帰還率を仮定（2010 年人口基準）	帰還困難区域（5 年以上帰還困難区域） 2020：帰還なし仮定；2030：20% 元住民帰還仮定 居住制限区域（数年後の帰還を目指す区域）	

	2020：40% 元住民帰還仮定；2030：60% 元住民帰還仮定 避難指示解除準備区域（早期の帰還を目指す区域 ） 2020：60% 元住民帰還仮定；2030：80% 元住民帰還仮定	
5. 未来人口予測	人口変動の傾向は 2010－2020 年 7.52% 減少； 2020－2030 年 16.99% 減少（2010 年を基準とし）。	[7]
6. 一次エネルギー消費量マップを作成	一次エネルギー消費量＝一人当たり一次エネルギー消費量（**表２**に参照）×福島県各年各地域人口 備考：予測は 2020、2030 年人口数値を使用。	

表２　一人当たり一次エネルギー消費量推計

日本全国	2010	2020	2030
人口推計[7]	128,060,000	124,100,000	116,620,000
一次エネルギー消費量推計[8]	501 Mtoe*	491 Mtoe	482 Mtoe
一人当たり一次エネルギー消費量推計	3.9 toe/person	3.96 toe/person	4.13 toe/person

*toe: ton of oil equivalent；石油換算トン。1toe≒41.87GJ≒11,630kW。

2.2　再生可能エネルギーのポテンシャル

再生可能エネルギーのポテンシャルは「潜在賦存量」と「利用可能量」に対する試算を行った。「潜在賦存量」は原則として技術的・社会的・経済的な条件を考慮しない賦存量である。GIS では、技術的･社会的な条件を加味し、「利用可能量」が算出できる。

太陽光発電

GIS データベース：国土地理院、基盤地図情報 25000。国土交通省、国土数値情報：標高・傾斜度 5 次メッシュ。平年値（気候）メッシュ（H24）。用途区域(H23)。土地利用細分メッシュデータ(H21)。森林地域。農業地域。都市地域。自然公園地域。自然保全地域。土砂災害危険箇所。

計算式　太陽光発電潜在賦存量[9]	=平均日射量（水平方向）	×自治体の面積	×365	×設備利用率	
[MJ/yr]	[MJ/m^2・day]	[m^2]	[yr]	[12%]	

「利用可能量」算出のオーバーレイ条件（メガソーラーの導入適地）

1. 都市計画区分：都市区域を除く。単純に「市街化区域」を除くではなく、「用途区域」も合わせ、「準工業地域、工業区域、工業専用区域」設置可能区域となった。
2. 傾斜度と向き：傾斜度 0－2.5%、向き任意；傾斜度 2.5－15%、南向き[10]。
3. 法規制等：農用地区域、保安林、自然保全地域、自然公園（特別保護区域）、土砂災害危険箇所を除く。
4. 土地利用：建物用地、道路、鉄道、その他用地、河川と湖、海浜、海水域、ゴルフ場を除く。
5. 面積 1.5ha 以上[11]。

風力

GIS データベース：国土地理院、基盤地図情報 25000。国土交通省、国土数値情報：標高・傾斜度 5 次メッシュ。土地利用細分メッシュデータ(H21)。森林地域。農業地域。都市地域。自然公園地域。自然保全地域。土砂災害危険箇所。鳥獣保護区。NEDO、風況マップ（500m メッシュ）。元データ（.dat）は.dbf 書式に転換し、GIS でメッシュ化した。

計算式　風力潜在賦存量[12]＝風車設置可能台数×1 台あたり年間発電量
＝風速ごとのメッシュ面積/（風車直径×10）^{2}×風速の出現頻度[13]×8760×風車出力曲線[12]
備考：試算は福島で既存数多く 2000kw 直径 90m 風車を使用。風車設置距離は 10 倍直径に仮定した。

「利用可能量」算出のオーバーレイ条件

1. 風速（70m）：6.0m/s 以上[14-15]
2. 傾斜度と標高：20%以下[14-16]；1000m 以下[14-17]
3. 都市計画区分：市街化区域外[17]
6. 法規制：農用地区域、保安林、自然保全地域、自然公園（特別保護区域）、土砂災害危険箇所、鳥獣保護区を除く[17]。
4. 土地利用：田、建物用地、幹線交通用地、その他の用地、河川及び湖沼、ゴルフ場、海水域不可。森林、海浜、荒地、そのた農用地可[17]。
5. バッファ距離設定：市街化区域など>2000m[18]；村>500m[17-19]；湖、川など>500m[10]；生態保全区域（国立公園特別保護区域、自然環境保全地域、鳥獣保護区）>1000m[10,18]；空港>2500m[15]；歴史区域>2000m[15,18-19].

バイオマス-森林バイオマス

GIS データベース：国土地理院、基盤地図情報 25000。国土交通省、国土数値情報：標高・傾斜度 5 次メッシュ。森林地域、農業地域、都市地域、自然公園地域、自然保全地域、鳥獣保護区。環境省生物多様性センター、植生調査第 5 回。NEDO、バイオマス賦存量・利用可能量の推計、森林成長量(1km メッシュ)
原子力規制委員会、放射線モニタリング情報、福島県空間線量測定結果(2013.12.11, 12 時データ)

計算式　森林バイオマス賦存量[9]＝森林成長量×重量換算×発熱量×10^{-3}
[GJ/yr]　[m^3/yr.]　[500kg/m^3] [MJ/kg] [GJ]
備考：針葉樹発熱量 19.78MJ/kg；広葉樹発熱量 18.80MJ/kg。

「利用可能量」算出のオーバーレイ条件

1. 森林区域抽出
2. 法規制：保安林を除く
3. 傾斜度：20%以下[16,20]
4. 森林空間線量：0.1uSv/h 以下 [21-22]

放射能物理的減衰計算式[23]　$N_t = N_0 \times 0.5^{\frac{t}{T}}$

N_tは時刻 t における原子数、N_0は時刻 t =0 の原子数、Tは半減期（セシウム 134, 2 年；セシウム 137, 30 年）。また、第 6 次(2012.11.16)の測定結果により、風雨等の自然要因による減衰したもの（年率約 15%）と考えられる[24]。本研究における森林の空間線量予測する時、風雨などによる年率 7.5%（第 6 次の半分）の自然減衰も考量した。

セシウム134とセシウム137の線量寄与率を考量し、下記の計算式で総合線量を試算した。 $R = Cs134 \times 70\% + Cs137 \times 30\%$

放射線予測結果に基づき、IDW法を使用し、2020年と2030年の森林空間線量ラスタマップを得た。

バイオマス–未利用・廃棄物バイオマス

GISデータベース: 国土地理院、基盤地図情報25000。NEDO、バイオマス賦存量・利用可能量の推計、稲わら、もみ殻、ササ、ススキ(1kmメッシュ) 未利用系・廃棄物系資源（市町村単位)。元データ(.xls)は.dbfデータに転換し、GISで福島市町村ポリゴンと合成した。

「利用可能量」算出のオーバーレイ条件：NEDOを提供したデータは「賦存量」と「有効利用可能量」両方含めているので、「期待可採量」は「有効利用可能量」の数値をそのまま使用した。

地熱

GISデータベース：国土地理院、基盤地図情報25000。環境省、H24年再生可能エネルギーに関するゾーニング基礎情報、地熱資源密度図。

計算式　地熱賦存量＝地熱資源密度×面積×8760×設備利用率 [kWh/yr]　[kW/km^2]　[km^2]　[h]　[70%]

「利用可能量」算出のオーバーレイ条件
1. 温度：50℃以上[17,25]
2. 傾斜度：20°
3. 都市計画区分：市街化区域外
4. 法規制：農用地区域、保安林、自然保全地域、自然公園（特別保護区域)、鳥獣保護区を除く
5. 土地利用：田、建物用地、幹線交通用地、その他の用地、河川及び湖沼、ゴルフ場、海水域不可。森林、海浜、荒地、そのた農用地可[17]。
6. バッファゾーン設定：温泉地1000m以上
7. 面積：0.5ha以上

水力

GISデータベース：国土地理院、基盤地図情報25000。環境省、H24年再生可能エネルギーに関するゾーニング基礎情報、中小水力、マイクロ水力(0-100kW)・ミニ水力(100-1000kW)を抽出した。

計算式　水力賦存量＝水力出力ポテンシャル×8760×設備利用率 [kWh/yr]　[kWh]　[h]　[50%]

「利用可能量」算出のオーバーレイ条件
1. 法規制：農用地区域、保安林、自然保全地域、自然公園（特別保護区域)、鳥獣保護区を除く

2.3 再生可能エネルギーの自給自足マップ（500mメッシュ）

計算式　自給自足率(%)＝一次エネルギー消費量/再生可能エネルギーの利用可能量合計

- 高自給自足率：スコア0-0.8 ;自給自足率>125%;
- 中自給自足率：スコア0.8-1.25 ;自給自足率80-125%;
- 低自給自足率：スコア>1.25 ;自給自足率<180%。

2.4　総合マップ

「利用可能量」算出の時、オーバーレイを通じ得た各再生可能エネルギーの導入可能区域レイヤを重ね、総合マップを作成した。また、既存再生可能エネルギー施設、最大熱供給距離10km[26]、避難指示区域、都市区域も入れた。

2.5　意思決定支援

試算数値、再生可能エネルギーの自給自足マップ、総合マップは今後福島再生可能エネルギーのビジョンづくり、再生可能エネルギー空間計画、住宅計画などの分野での活用が期待できる。

3. 結果

3.1 一次エネルギー消費量

上記 2.1 の手順に従って、人口と一次エネルギー消費量は**表 3** に参照。2020 年、2030 年まで両方とも徐々に減少の傾向が分かった。避難人口の帰還率の仮定により、相双地区は 2020－2030 年の間、人口と一次エネルギー消費量少し増加の傾向することが分かった。

表 3　福島県における人口と一次エネルギー消費量予測結果

地区	区域区分	人口			一次エネルギー消費量（GJ/yr.）		
		2010	2020	2030	2010	2020	2030
会津	会津	262,051	249,117	223,607	42,791,559	41,304,906	38,666,877
	南会津	29,893	27,645	24,814	4,881,163	4,583,692	4,290,945
中通り	県北	497,059	474,225	425,860	81,166,125	78,628,979	73,641,111
	県中	551,745	523,803	470,245	90,095,740	86,849,387	81,316,276
	県南	150,117	140,001	125,665	24,512,959	23,212,869	21,730,327
浜通り	相双	202,773	142,009	142,823	33,112,178	23,545,885	24,697,479
	いわき	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

3.2 潜在賦存量

上記 2.2 の試算方法に従って、潜在賦存量の試算結果は**表 4** の通り。資源の空間分布は**図 5** に参照。太陽光とバイオマスは県内多く潜在賦存量を持つことが分かった。それから、風力、地熱、ミニ・マイクロ水力も多く県内に存在している。

表 4　福島県における再生可能エネルギーの潜在賦存量試算結果

地区	区域区分	太陽光 (GJ/yr.)	風力 (GJ/yr.)	バイオマス（GJ/yr.）		地熱 (GJ/yr.)	水力 (GJ/yr.)
				森林	未利用・廃棄物		
会津	会津	1,649,380,413	1,335,567	5,672,292	6,765,281	4,031,570	1,734,745
	南会津	1,301,851,592	1,205,125	1,851,971	2,098,939	921,606	2,761,851
中通り	県北	875,823,528	785,558	3,531,325	4,750,331	467,028	462,833
	県中	1,454,652,744	1,533,576	6,679,078	8,283,394	143,910	359,587
	県南	690,962,002	553,976	3,952,520	4,956,428	19,249	152,787
浜通り	相双	985,262,414	1,059,140	4,897,303	5,761,468	1,238	238,846

	いわき	689, 691, 755	606, 831	4, 113, 452	5, 984, 101	35, 257	243, 585
合計	–	7, 647, 624, 448	7, 827, 791	30, 697, 941	38, 599, 942	5, 619, 858	5, 954, 234

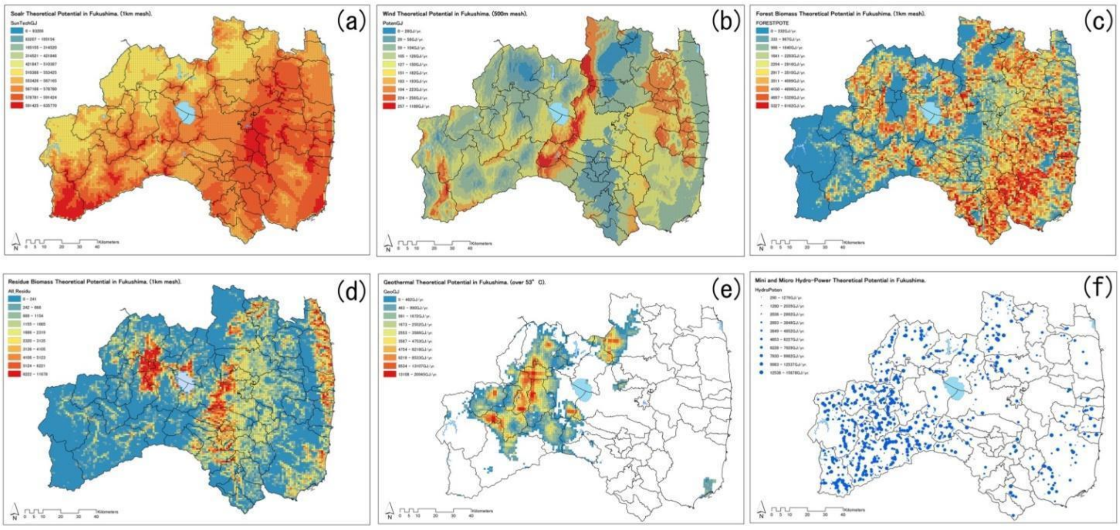

図 5　福島県における潜在賦存量の空間分布図（a. 太陽光；b. 風力；c. 森林バイオマス；d. 未利用・廃棄物バイオマス；e. 地熱；f. ミニ・マイクロ水力）

3.3 利用可能量

上記 2.2 の算出条件をオーバーレイし、各再生可能エネルギーの利用可能量は**表 5** に参照。放射能予測図は利用可能森林範囲を重ね合わせ、**図 6** を得た。利用可能資源の空間分布は**図 7** に参照。

表 5　福島県における再生可能エネルギーの利用可能量試算結果

地区	区域区分	メガソーラー (GJ/yr.)	風力 (GJ/yr.)	バイオマス(GJ/yr.) 森林 (2020)	未利用・廃棄物	地熱 (GJ/yr.)	水力 (GJ/yr.)
会津	会津	12, 155, 400	93, 742	1, 143, 591	2, 742, 340	1, 664, 734	1, 244, 265
	南会津	2, 612, 457	45, 108	348, 803	464, 288	499, 986	1, 724, 135
中通り	県北	8, 449, 481	61, 982	946, 895	1, 304, 350	89, 005	245, 175
	県中	21, 018, 417	273, 709	2, 764, 895	3, 242, 402	42, 183	225, 566
	県南	16, 376, 603	83, 800	1, 606, 596	1, 163, 934	11, 474	92, 090
浜通り	相双	28, 279, 549	302, 983	992, 506	1, 834, 251	724	124, 723
	いわき	14, 234, 210	151, 444	1, 610, 949	837, 067	11, 873	187, 230
合計	–	103, 126, 117	1, 012, 768	9, 414, 235	11, 588, 632	2, 319, 979	3, 843, 184

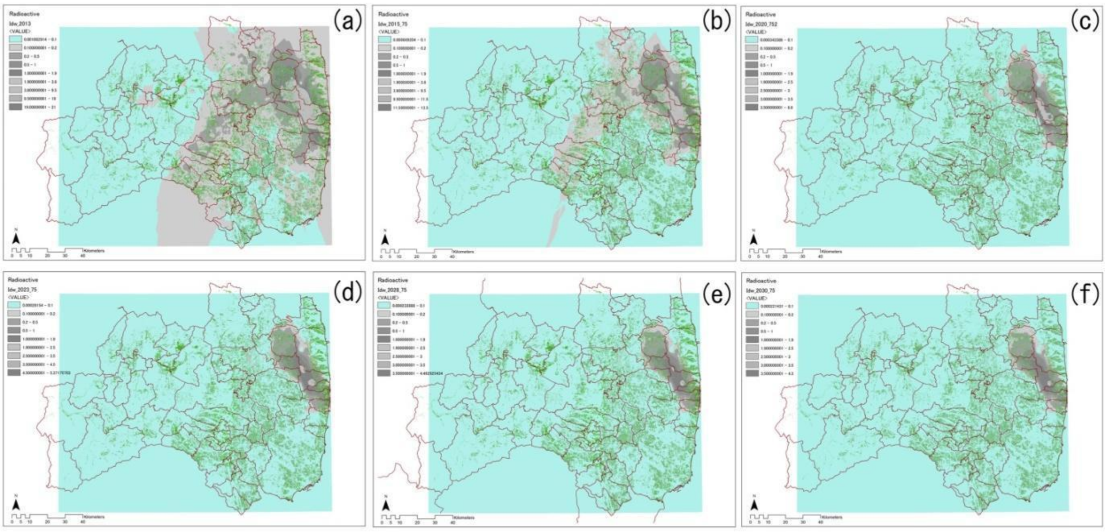

図 6　福島県における放射能予測図と森林（放射能レベル以外の条件オーバーレイ済み）の組み合わせ図。（a. 2013;b. 2015;c. 2020;d. 2023;e. 2028;f. 2030.）グレーは放射能レベル 0.1uSv/h 以上の区域、青色は放射能レベル 0.1uSv/h 以下の区域。緑色は放射能レベル以外の条件オーバーレイ済みの森林区域を示す。

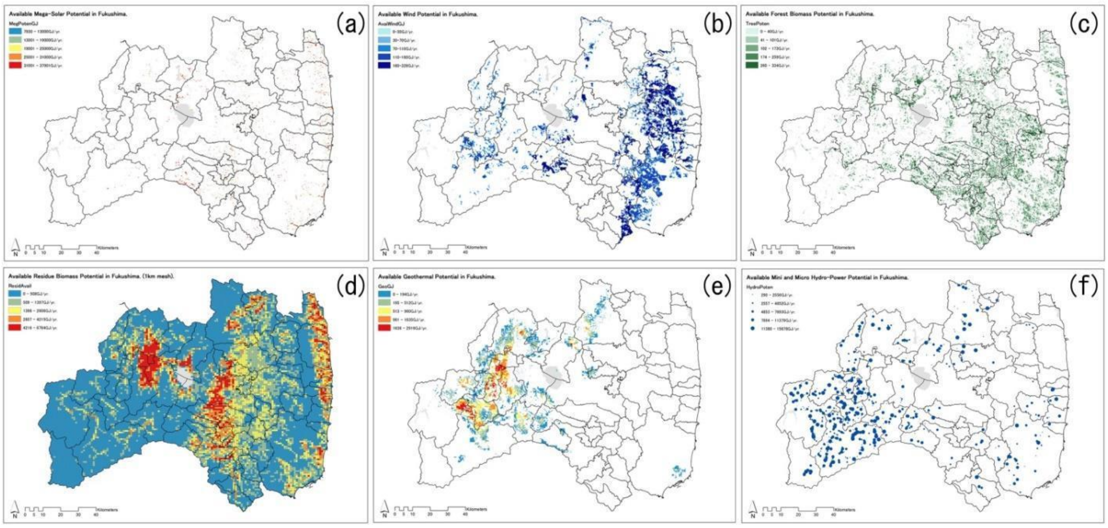

図 7　福島県における利用可能量の空間分布図（a. 太陽光；b. 風力；c. 森林バイオマス；d. 未利用・廃棄物バイオマス；e. 地熱；f. ミニ・マイクロ水力）

3.4 再生可能エネルギーの自給自足マップ

一次エネルギー消費量とすべての再生可能エネルギー利用可能量は GIS を使用し、500m メッシュに統計した。それから消費量レイヤと利用可能量レイヤをオーバーレイし、**図 8** のように県内 2020、2030 年自給自足マップを作成した。自給自足マップに基づき、県内の区域別と自給自足率別は**表 6** にまとめた。高自給自足地区と低自給自足地区は県内で混在している。分布特徴とし、高自給自足地区はよく会津地区に分布し、低自給自足地区は数多く中通り地区に分布していることが明らかにした。

3.5 総合マップ

条件オーバーレイに通じ得られた各エネルギー（メガソーラー、風力、バイオマス、地熱、水力）の利用可能範囲を一つマップに乗せ、また、既存再生可能エネルギー施設、最大熱供給距

離 10km[25]、避難指示区域、都市区域も加え、最終総合マップを作成した（**図 9** ）。マップは今後福島再生可能エネルギーのビジョンづくり、再生可能エネルギー空間計画、住宅計画などの分野への意識決定支援の活用が期待できる。

表 6 2020、2030 年まで自給自足地区区分

地区	区域区分	高自給自足地区		中自給自足地区		低自給自足地区	
		2020	2030	2020	2030	2020	2030
会津	会津	10.0%	10.1%	1.5%	1.4%	11.0%	10.9%
	南会津	13.1%	13.1%	0.3%	0.3%	3.7%	3.6%
中通り	県北	1.9%	1.9%	0.4%	0.4%	10.4%	10.3%
	県中	5.1%	5.1%	0.6%	0.8%	11.4%	11.3%
	県南	2.1%	2.2%	0.5%	0.5%	6.3%	6.3%
浜通り	相双	6.0%	4.8%	0.6%	0.9%	6.2%	7.1%
	いわき	1.5%	1.5%	0.8%	0.8%	6.6%	6.7%
合計	-	39.7%	38.7%	4.7%	5.1%	55.6%	56.2%

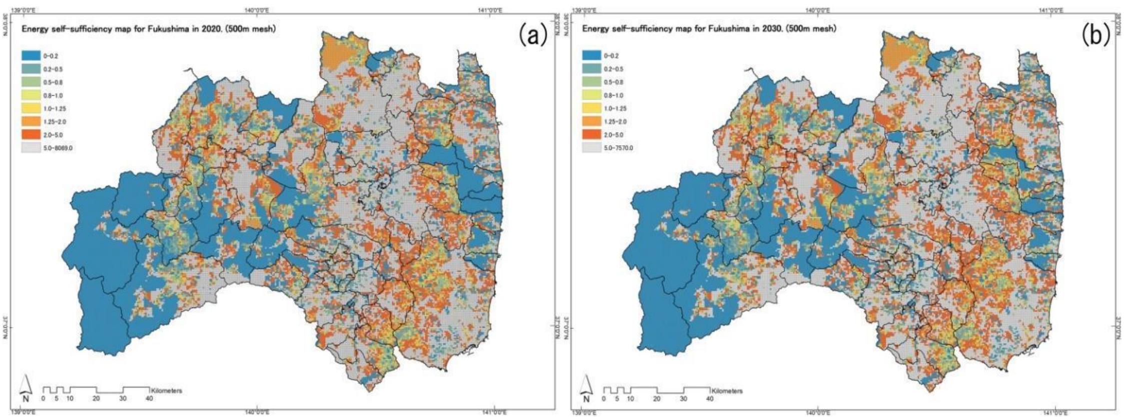

図 8　福島県における 2020 年、2030 年の自給自足マップ（a. 2020 年；b. 2030 年）

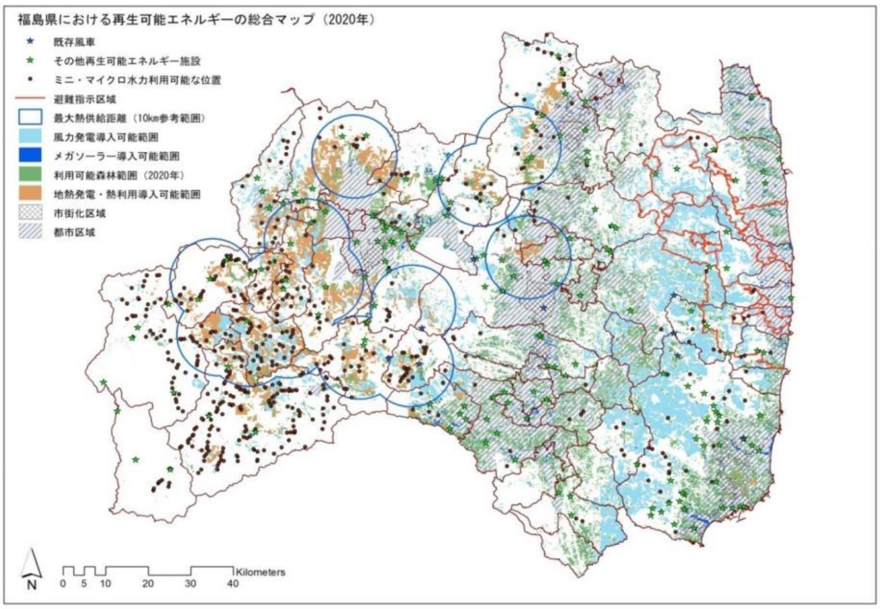

図 9 福島県における再生可能エネルギーの総合マップ（2020 年まで使用可能な森林区域を使用）

5. まとめ

本報告書から､再生可能エネルギーの自給自足マップ及び総合マップの作成に GIS を活用することで､各種再生可能エネルギーの利用可能量､導入可能範囲､及びその位置関係を分かりやすく可視化することができ､再生可能エネルギーの総合的利用の施策立案に有効と考えられる｡多様な再生可能エネルギーを積極的に活用していくことが持続可能な社会に向けて､経済性､環境性､生態系なども踏まえた導入可能性､シナリオ分析を検討していくことが､今後は必要だと考えられる｡再生可能エネルギーの導入により､福島県震災以後の復興にとっても重要な一環である｡

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