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Visual Impact Evaluation of Wind Farms: a Case Study of Choshi City, Japan

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Abstract
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 to local levels. There is also lack of integrated visual impact evaluation method at both city and community levels. To solve these problems, this study focused on local areas and proposed a GIS-based integrated methodology for visual impact evaluation of wind farms at both city and community levels. At the city level, we carried out an evaluation by quantifying change of wind turbine visible area (Zone of Visual Influence) of wind farms using GIS Viewshed Analysis. At the community level, we evaluated the visual impact of wind farms using the Spanish Method, combined with a questionnaire survey. Although wind energy is developing at a quick pace in some Asia countries, visual impact related research has been lacking. In Japan, Wind energy may become a popular energy source for local use in the coming few decades and play a vital role in the post-earthquake reconstruction. For this reason, we verified the above methodology with Choshi City in Japan as the case study, thus providing empirical evidence of applying the Spanish Method in an Asian country. This methodology facilitates understanding of the visibility conditions of wind farms' infrastructure to planners, investors, and policy makers, hoping to contribute to expansion of knowledge on visual impact evaluation of wind power facilities that might become important in the future cities.
Keywords: Visual impact evaluation, GIS, viewshed analysis, wind farm, Japan.

1. Introduction

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 and 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 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 (Lothian, 2007; Moller, 2006). 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 method 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 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, 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).

Each of the above methods has different characteristics. We infer a combination of those methods so as to benefit from their advantages. In this study, a new methodology that combines two levels of visual impact evaluation is proposed. This new hybrid methodology is composed of 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 has no consideration for different landscape backgrounds such as wind turbines layout factors, we combined it with a questionnaire survey for the community level evaluation to make up for this deficiency. Finally, the proposed methodology was applied to Choshi city in Japan as the case study. Therefore, 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.

2. Study area

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 Fig.1. At the community level, we selected Sarudacho and Tokoyodacho settlements located in the west of Choshi City. 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 in the middle of all the wind farms, thus a high exposure to the wind turbines. This community has mixed farmland and forest landscapes with a combined hilly and flat topography.

3. 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 Fig.2.

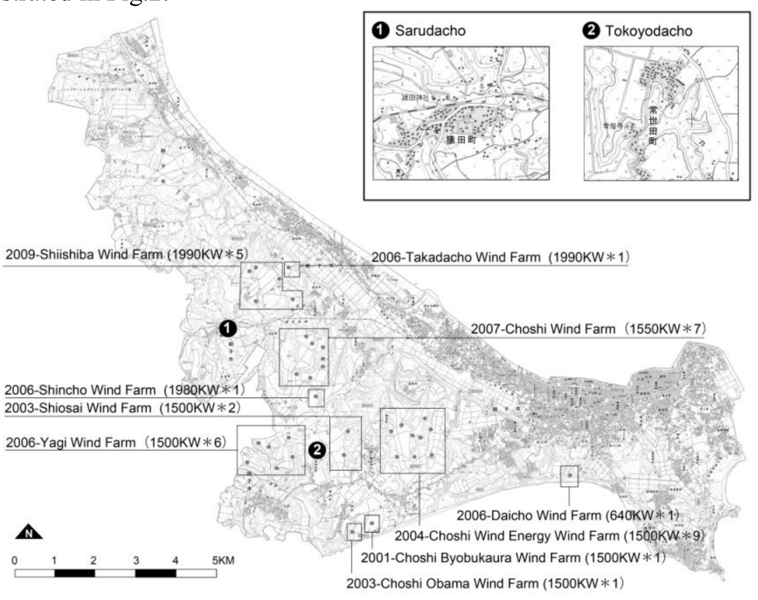

Fig.1. Wind farm and community map.

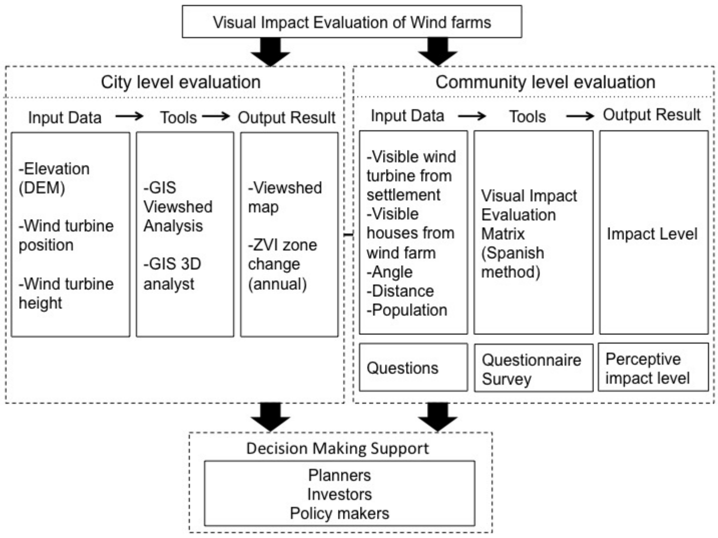

Fig. 2. Methodology framework for visual impact evaluation at both city and community levels.

3.1 GIS Viewshed analysis

Viewshed analysis is an 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 into ArcGIS and edited elevation attribute for each of them. We generated Triangular Irregular Network (TIN) from the contours (Fig. 3) 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 1). 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 based on Raster data, and output an annual Viewshed map. In the meantime, total wind turbine visible area was calculated as ZVI.

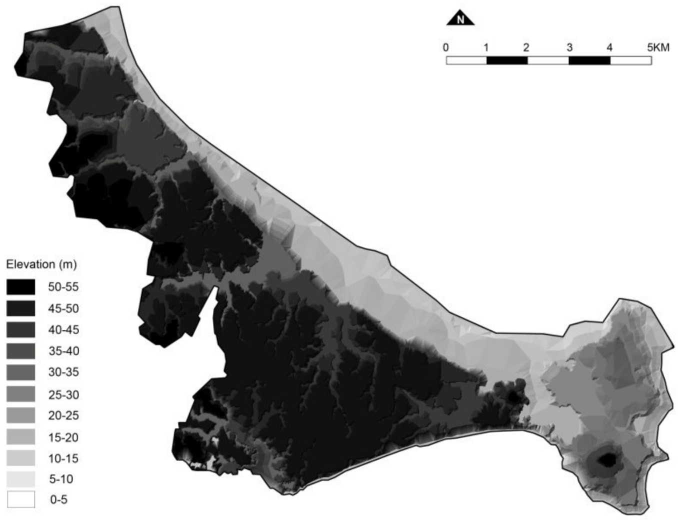

Fig.3. TIN map of Choshi city.

Table 1. Wind turbine location sample (NEDO, 2010).

Year	Wind farm	Number of wind turbines	Location
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
2003	Shiosai1	1	35°42′28.0″N, 140°46′8.0″E
	Shiosai2	1	35°42′14.0″N, 140°46′3.0″E

3.2 Spanish method

At the community level, we applied the Spanish method to Sarudacho and Tokoyodacho settlements in suburban Choshi. Spanish method (Hurtado et al., 2004) proposed "Visual Impact Evaluation Matrix (VIEM)" suitable at the community level. VIEM has five coefficients: a) Visibility coefficient of wind farm from settlement; b) visibility coefficient of the village from wind farm; c) visibility coefficient of the wind farm taken as a cuboid; d) distance coefficient between the wind farm and the village; e) population coefficient of the village. Partial assessment 1 (PA1)=a *b*c *d, and Partial assessment 2 (PA2)=a *b* c *d *e. According to PA1 and PA2 scores, the visual impact level can be determined, see Table 2.

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 main road and significant community spots such as the JR train station, 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 survey on Nov 6, 2010 and Dec 5, 2010. See Fig. 4 and Fig.5. 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 (Fig. 1)" 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 2. Determination of the impact level (Hurtado et al., 2004).

PA	Impact level	Comment
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 reasons for carrying out the installation of thewind farm.

3.3 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, and dropped into the mailbox in front of each household randomly through walking around the community areas. Each questionnaire package included an explanation letter, a questionnaire sheet and mail-back envelope with 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, where five impact levels: deep, serious, medium, light, and minimum were used. 4) Evaluation of wind farms visual impact levels on a particular landscape scenario. We also included evaluation of visual impacts 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 a coefficient provided for in the Spanish method. For landscape scenarios, five typical landscape types in Choshi city were selected including farmland, residential, urban, road,

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and Satoyama (forest and farmland) areas. Each landscape's background picture was taken in Choshi city, and had wind turbines implanted in it using Photoshop CS2 to create five varying scenarios, see Fig. 6. For layout scenarios, a general landscape background picture of Choshi suburban area was used, and had six wind turbines implanted in it using Photoshop CS2 to create varying layouts, see Fig. 7.

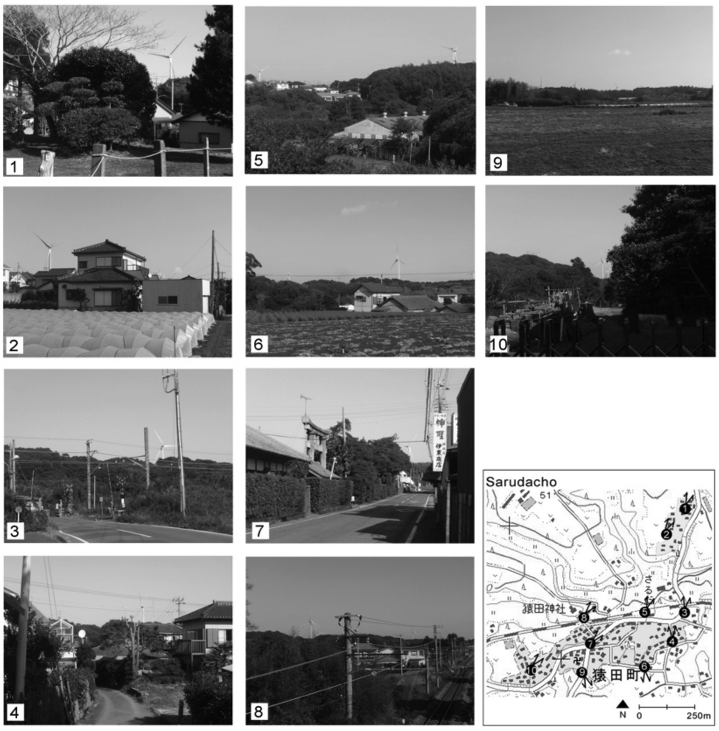

Fig.4. Picture sample for each viewpoint in Sarudacho.

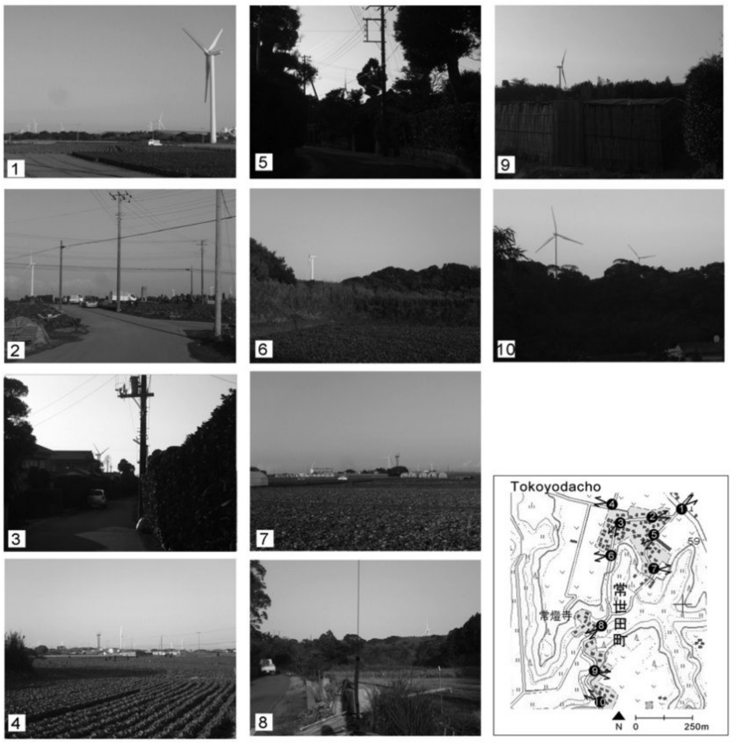

Fig.5. Picture sample for each viewpoint in Tokoyodacho.

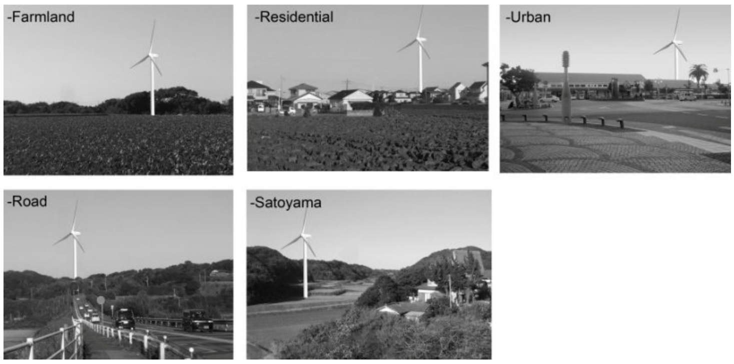

Fig.6. Photomontage for different landscape type scenarios.

Fig.7. Photomontage for different layout scenarios.

4. Results

4.1 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 Fig. 8. In 2001, when there was only one wind turbine in Choshi city, the turbine visible 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, through comparing ZVI area and wind turbine number from 2001 to 2009, we found that ZVI area increased at an average rate of 14.9% along with wind turbine numbers increase from 2001 to 2006. On the other hand, ZVI area just increased at an average rate of 0.9% along with wind turbine numbers increase from 2006 to 2009. The ZVI area increase rate decelerated after 2006, see Table 3.

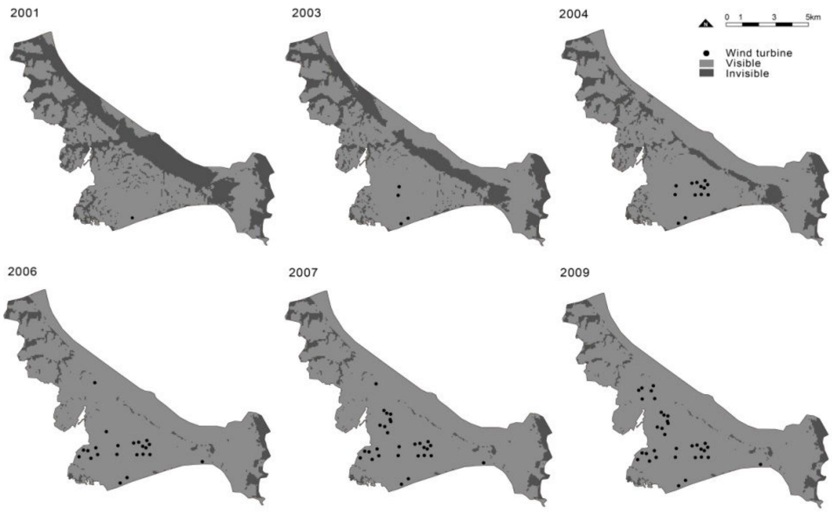

Fig.8. Wind turbine visible area change from 2001-2009 in Choshi City.

Table 3. Wind turbine visible area and wind turbine numbers.

Year	ZVI (km^2)	Percentage of city area[a]	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

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

4.2 Spanish method results

Through site survey, we found that only three wind farms: Shiishiba, Takadacho, and Choshi wind farms were visible from Sarudacho. Thus, we only considered these three wind farms 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 process. Results from application of Spanish method in Sarudacho are as shown in Table 4, and those from Tokoyodacho are as shown in Table 5. We 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 4. Evaluation results from Sarudacho.

Wind farm	a	b	c	d	e	PA1	PA2	Impact level
Shiishiba and Takadacho	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 5. Evaluation results from Tokoyodacho.

Wind farm	a	b	c	d	e	PA1	PA2	Impact level
Shiishiba and 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

4.3 Questionnaire results

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 were 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 6. 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 7. 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 8.

Table 6. 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 7. Evaluation 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 8. Evaluation results of different layout scenarios (N=63).

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

5. 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 4 and Table 5) to those from the questionnaire survey (Table 6) 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". Therefore, there is a disparity between the two evaluation methods as revealed by the difference in results, visual impact level of wind farms to residents' perception is deeper than the level revealed by Spanish method. This study got different results to those of the research done in Crete island of 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. Hence 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.

6. Conclusions and recommendations

Based on the findings, we conclude 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.

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. 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. We highlight 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.

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