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A Study on Visual Impacts of Wind Turbine Arrays in Offshore Wind Farms

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Abstract. Although offshore wind energy is one of the promising renewable energy sources, there are some opponent opinions due to some reasons, including "disturbance of landscape." Such opinions should not be ignored for public facilities. However, landscape is a value that cannot be quantified easily. Array patterns of wind turbines are determined due to terrains, wind conditions, avoidance of wake, etc., not because of the landscape. The authors apply a method called "induction field of vision" to wind turbine arrays to extract numerical features of the shape. Correlation of the numerical features and the observer's preferences were calculated. The preliminary results showed that the regular pattern has a weaker impression than the irregular pattern, and more preferred to. Although the tendency itself is natural, the important fact is that the reason of preference can be explained numerically. This paper investigates the observer's preferences more precisely by the photos combining practical landscapes with virtual wind turbine arrays using Virtual Reality. Through this effort, the study clarifies which array patterns can ease disturbance of landscape. Since there are many offshore wind farm projects following the approved three projects, the obtained information will be useful in considering the acceptable array designs of the next offshore wind farms, which have less impacts on landscape and are symbiotic with local communities.

Keywords. Offshore wind, wind turbine array, induction field, observer's preference, landscape disturbance

Introduction

Japan is, as well as other countries in the world, strongly focusing on renewable energy sources to prevent climate change. Offshore wind power is one of the most promising energy sources, in terms of geological potentials and technical feasibilities. Three major offshore wind farm projects have been launched and two of the are located in the offshore of Akita prefecture. Japanese projects are of landing type and relatively close from the seashore. So. some opposing opinions name "landscape disturbance" as the avoidance factor of offshore wind farms.

However, unlike the "noise" that has certain criteria for human health and comfortability, beauty of a landscape is a very personal feeling and difficult to quantify. If it is possible to clarify what is the definition of "landscape disturbance" and how can we avoid it, it would be a useful information to enhance social acceptance of offshore wind farms by designing acceptable arrangement. There some previous studies [1-3] that focuses on landscape evaluation related to wind turbines, and have obtained significant outcomes. This study also targets such objective to quantify the values of landscapes

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especially focusing on the area where the offshore wind farm project is ongoing. In order to extract visual features from virtual and simplified pictures of wind turbine arrays, this paper uses a theory called induction field of vision [4]. In the previous studies [5], the method was applied to other products such as smartphones and office chairs. By comparing the extracted numerical features with the results of the questionnaire to know the customer preferences, it was possible to know what kind of product shape is preferred because of what kind of reasons. Then, the method is applied to virtual wind turbine arrays, in this paper, then, it will be possible to identify relatively preferred arrangement of wind turbines theoretically.

Of course, the wind turbine arrays of offshore wind farms are not decided by the evaluation of landscape, but decided to avoid the wake effects, or in seeking for suitable terrains. But, if it is possible to assure that the preferred arrangement is not affected by the other functional reasons, landscape evaluation can be significant criteria to determine the arrangement of wind turbine arrays.

1. Situation of Japanese offshore wind farms

In line with other countries in the world, Japan is trying to put emphasis on renewable energy sources as one of the climate change countermeasures. Offshore wind energy is thought to be one of the major and promising energy sources. Three locations have been selected for the first-round projects to install large scale offshore wind farms in Japan, among several candidate locations. Seashore of Akita prefecture includes 2 locations among the first three. In December 2021, business alliances to run the project have been assigned through a bid. Thus, Akita prefecture is the top runner regarding the Japanese offshore wind. Although the projects are expected to boost regional economy, there are some opposite opinions from the local community.

Since there are some following projects in round-two, round-three, and so on, Akita's cases are the touchstones to overcome the avoidance factors and find the acceptable solutions for the local communities. Therefore, even if the reason of opposing is "landscape disturbance" which is difficult to quantify and rather vigorous, it should not be ignored.

2. Avoidance factors of wind farms

In a previous study [6], the relative weights of 5 major avoidance factors were quantified as Figure 1. "Disturbance of landscape" has the lowest weight among the five major factors, both for residents and for visitors mentioned in the same paper [6]. But among these five major factors, quantitative discussion is possible for other factors, such as "noise," "vibration"," and so on. Contrarily, "landscape" is a very personal feeling and difficult to quantify. Without a quantitative evaluation, it is difficult to discuss whether the plan is acceptable. In addition, since both results were about onshore wind farms, the avoidance factors for offshore wind farms can be different. By constructing the wind farms at certain distances from the residential area, importance of "noise" and "vibration" can be lower, that may highlight the importance of "landscape disturbance." In fact, a newspaper article [7] mentions opposing groups name "disturbance of landscape" as the first reason to oppose to the offshore wind farm projects ongoing in the offshore of Akita prefecture. The survey was made to 78 university students and 20 residents who live near

the existing onshore wind turbine. Among 20 respondents one person answered "landscape" is the most important factor, and 3 answered it is secondly important, while 13 of 20 said it is least important. So, the feature of the factor "landscape disturbance" is that it has large individual differences. On the other hand, quantitative analysis of landscape as the base of discussion, has not been conducted by energy provider, nor local government. Disrespect of "landscape" can be a reason for residents to oppose for the project.

Therefore, numerical analysis of landscape may provide useful information for wind power projects to ease the opposite opinions and acceptable solutions for residents and energy service companies.

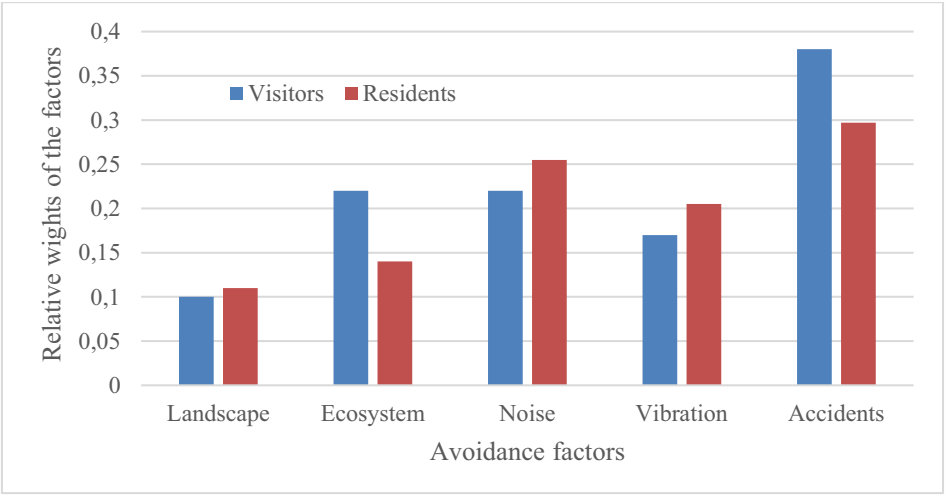

Figure 1. Weights of avoidance factors of onshore wind farms.

3. Proposing evaluation method; induction field of vision

3.1. Basics of the theory

"Induction field [4]" is a phycological concept that assumes a field like an electro-static field around a certain shape, in order to explain pattern recognition mechanism of human vision. Although letter fonts are different, or hand writings of human have different shape one by one, human eyes can recognize same letter as the same. It is assumed that similar induction fields around the shapes enable this. Although the shapes themselves are different, induction fields arouse by the shape are similar. In such cases, even though the letter fonts are different, human can recognize the same letters are the same. That is thought to be the background of human recognition.

3.2. Numerical calculation of the induction field

In the previous study [8] a mathematical model to express the induction field arouse by watching a certain shape was proposed as eq.(1). Using the equation, one of the authors has analyzed the correlation between product shapes, numerical features extracted from

the shape using the theory and the preferences of the users, in preceding studies. It is said that the integral of the induction field expressed by eq.(2) basically corresponds to the "overall strength of the impression," while the peak-to-peak value in eq.(3) expresses the "sharpness of the shapes."

The method was applied to analyze different arrangement patterns of wind turbines to analyze the differences of shape impressions of the patterns.

$$S(x,y) = \iint_{\Delta s} \left\{ \exp\left(-\frac{(\xi-x)^2+(\eta-y)^2}{2*5^2}\right) - \frac{5^2}{14^2} * \exp\left(-\frac{(\xi-x)^2+(\eta-y)^2}{2*14^2}\right) \right\} L(\xi,\eta) d\xi d \quad (1)$$

$S(x,y)$: strength of the indcution field
x,y: coordinate values on the XY plane of a certain point in the shape
ξ,η: coordinate values of a certain retinal photoreceptor cell
$L(\xi,\eta)$: value of the stimulas of the corresponding retinal photoreceptor cell

$$PE = \iint_0^{+\infty} |S| \cdot A(|S|) d([S]) \quad (2)$$

$$DI = S_{\max} - S_{\min} \quad (3)$$

4. Some patterns of wind turbines and its features

4.1. Different arrangement patterns

It is basically said that symmetrical or ordinal shapes may generate comfortable feelings to watchers compared to random shapes. The first important question is whether this fact is also true for wind turbine arrays, or not. In order to clarify this point, some virtual pictures of wind turbine arrays were analyzed. Figure 2 to 5 are the virtual array figures.

Figure 2. Irregular arrangement of wind turbines.

Figure 3. Irregular arrangement of wind turbines.

Figure 4. Regular arrangement of wind turbines.

Figure 5. Irregular arrangements of wind turbines.

4.2. Result of the induction field calculations

Induction field is a concept in cognitive science to explain how human vision recognize shapes. This study also analyzed the aforementioned pictures and calculated the corresponding distributions of induction fields, as Figure 6 to 9.

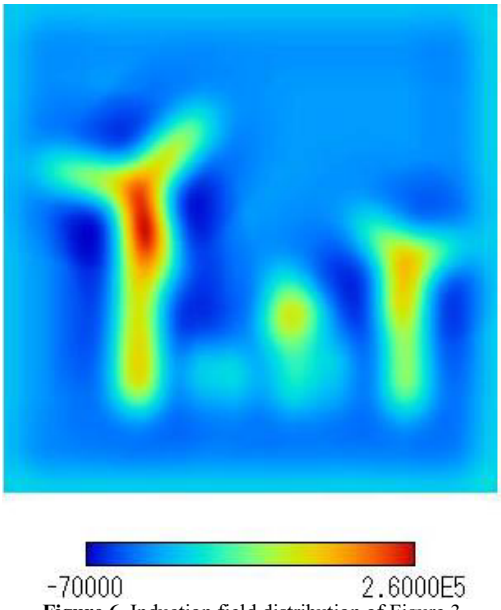

Figure 6. Induction field distribution of Figure 3.

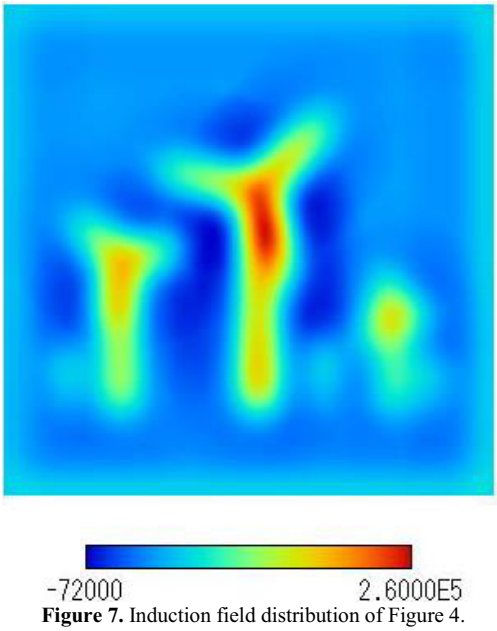

Figure 7. Induction field distribution of Figure 4.

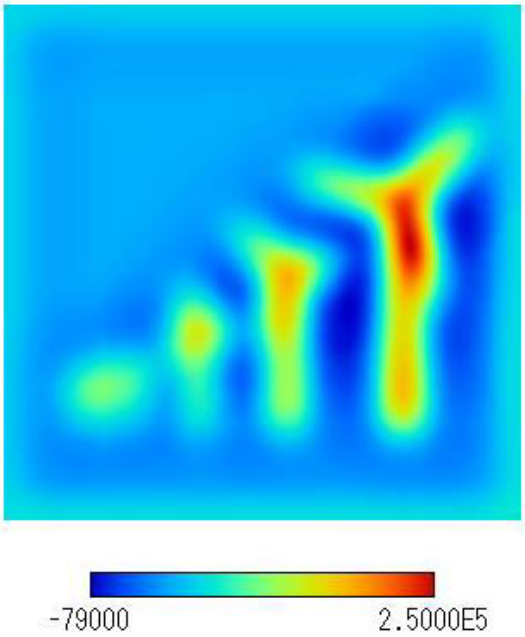

Figure 8. Induction field distribution of Figure 5.

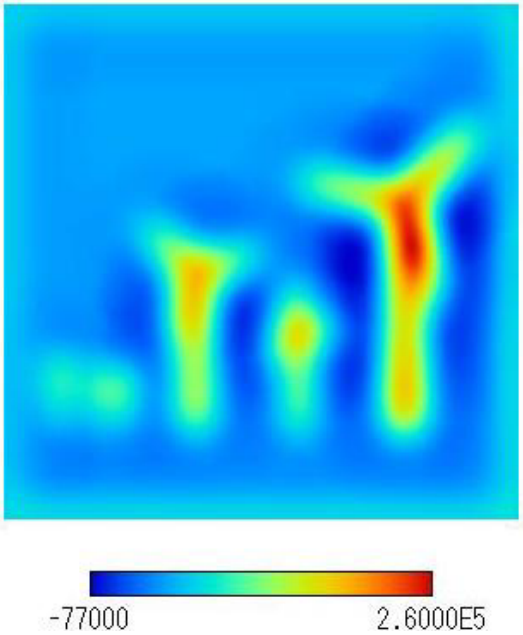

Figure 9. Induction field distribution of figure 6.

4.3. Correlations with the respondents' preference

The study also clarified the respondent's preference to the four figures shown in the previous section. The questions were asked to university undergraduate students. In order to avoid so-called "carryover effect," the questions were carried out to different

respondents. The date of the survey was before the announcement of the offshore wind farm projects in Akita prefecture. Thus, the respondents are non-stakeholders of the offshore wind farm projects. However, throughout the pre-survey of this study, it has become clear that some of the local businesses are expecting to call in young age visitors by using the "sunset with offshore wind turbines" as tourism resources. Thus, university students can represent future stake-holders of local tourism. The perceptions were quantified by the number of respondents who answered "like" and "dislike." These values were indicated with the corresponding *PE* value calculated by eq. (2). Table 1 below shows the respondent's preferences and corresponding *PE* values of the four figures. Table 2 shows the calculated correlation coefficients. The values in the table shows the strong negative correlation between the number of respondents who liked the figures. It also had the strong negative correlations with the difference of liked and disliked.

Table 1. Calculated PE and preferences.

Figure number	Number of respondents who liked	Number of respondents who disliked	$PE(\times 10^{12})$
2	19	13	5.20
3	19	8	5.25
4	43	12	5.11
5	4	39	5.36

Table 2. Calculated correlation coefficients.

Figure number	Correlation coefficients
With number of respondents who liked	-0.96
With number of respondents who disliked	0.77
With difference of liked and disliked	-0.95

5. Discussion

As it was mentioned in the previous section, *PE*; the integer of induction field distribution, showed a strong negative correlation with the respondent's preference. Since *PE* shows the overall strength of the impression, it means that people prefer weak impressions to strong impressions. Although this fact itself is very natural, the important fact is that this tendency can be reproduced by numerical analysis. By calculating the induction fields of the virtual array figures, it might be possible to estimate the preference of the people.

The number of data is insufficient to calculate the correlation precisely. However, this can be the first step to quantify the preference of the landscapes and then, to ease the avoidance feelings of offshore wind farms due to landscape disturbance.

Necessity to install renewable energy facilities in Japan is recognized by most of the people. However, such measures should not sacrifice the living environment of residents. On the other hand, there is a preceding study [9, 10] that clarified a renewable energy facility is relatively acceptable for observers compared to other artifacts. In addition, these artifacts are positively evaluated as a part of landscape, recently. This idea is called "technoscape [11]" and thought to be a category of scenic beauty. These conclusions suggest that by considering the harmonious arrangements of wind turbines which can ease the negative feelings of the residents, it can push the offshore wind farm projects forward. Even if the harmonious array reduces some power generation capacity, it is meaningful to adopt such way, when it is clearly preferred by residents.

6. Summary

The study focused one of the avoidance factors of offshore wind farms, so-called "landscape disturbance."

The people's perceptions for landscape were quantified by using the theory based on cognitive science called induction field of vison. Four figures of virtual wind turbine arrays were numerically analyzed based on the theory. The calculation results suggested that regular arrangement of wind turbine has relatively weaker impression compared to irregular arrangement. The respondent's preferences were compared with this numerical feature extracted from the induction field. The values showed strong negative correlations. Therefore, it can be estimated that regularly arranged array that has relatively weak impression, is more preferred by the observers.

Since this is a preliminary analysis with small amount of data, more precise investigations are necessary to conclude. As it was mentioned in the paper, the questionnaire to quantify the preference of virtual wind turbine figures was made to non-stakeholders. Stakeholder's opinion might be different. Preference can be also different if the figures are indicated with the actual landscape. Detailed interviews using virtual reality photos that combine actual photos of the target landscapes with offshore wind turbines can be helpful. However, this paper can be an important step to carry out the cooperated constructions of public facilities such as offshore wind farms.

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