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# Evaluating the Visual Impact of an Offshore Wind Farm

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**Abstract**

The objective of this paper is to present a method that qualifies the degree of visibility of an offshore wind farm from an observer located along the coast. In many cases, the deployment of an offshore wind farm leads to public opposition. This entails the need for the development of appropriate methods that might present in the most intelligible way the impacts of an offshore wind farm. Amongst many factors to take into account, the visual impact of such farms is surely a factor to take into account. We introduce a visual operator that integrates several parameters that mainly depend on the distance of the wind farm to the coast. We apply a measure that evaluates the horizon surface impact modulated by the number of distinguishable turbines and an aesthetic index based on turbine alignments. The whole method is implemented on top of Geographical Information System (GIS) and provides a decision-aid mechanism oriented to decision-makers. The whole approach is experimented in the context of a wind farm in North West France.


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*Keywords:* Visual impact; Offshore Wind Turbine; GIS; Seascape; Aesthetic; Decision-aid System

## 1. Introduction

It has been long observed that marine renewable energy could make a significant contribution to energy production [1], [2]. The technological development of offshore wind turbines has rapidly increased generating many economic challenges [3], novel approaches for the ocean management [4], as well as public concerns regarding possible environmental impacts [5], [6], [7].

The management of the maritime and littoral environments generates many conflicting issues due to rapid development and pressure on these areas. Indeed, any new activity close to the coast might generate many socio-economic conflicts. Among the principal reasons of social reluctance, the visual impact on the seascape could entail the successful development of a marine renewable energy project. In fact, seascape protection has become an important issue in many countries [8]. An appropriate evaluation of the visual

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impact of a wind farm project is one of the first steps to develop for engaging discussions with the general public and local stakeholders in order to study and even decrease any visual damage that may constitute the deployment of an offshore wind farm in the seascape.

The objective of the research presented in this paper is to introduce a method that quantifies the visual impact on the seascape of an offshore wind farm. The problem is not completely new at hand as many researches have been recently oriented to this issue [9]. However, the main challenge that still arises comes from the subjective part of problem. One might apply a series of surveys on population samples. This has been done using photomontages approaches [10], [11] or 3D visualization tools [12]. In this paper, we introduce a computational method that might be qualified as objective, and it can be considered as a preliminary process at the design phase of a given project of a wind farm, as well as a complementary approach to the ones mentioned above.

The technique developed in this paper provides a computational visual impact operator derived from a series of quantifiable indicators. Several parameters are considered such as the surface covered and the arrangement of the wind farm as well as its perception from the horizon as perceived from the coast. The way turbines are potentially perceived and qualified are taken into account and quantified, an aesthetic factor denotes the visual alignment of the turbines. The whole approach is implemented on top of a GIS environment that has the advantage of providing appropriate functions for managing, manipulating and deriving task-oriented operators.

## 2. Methodology

The methodology developed in this paper is first based on the evaluation the horizon occupation which mainly depends on the distance of the energy farm to the coast, height of the turbines and farm layout. We assume that observers are located along the shore line although the method can be applied to different constraints with some minor adaptations. No obstacles are supposed to alter the farm vision of the observers. The aim is to estimate the horizon occupation of the wind farm considered as a visual plane located at one meter of observer. The proposed visual index is based on a notion of horizon occupation refined by the number of distinguishable turbines and their arrangement considered as an aesthetic index.

### *2.1. Horizon occupation*

Let us consider the wind farm as a whole object of study. The spatial distribution of the wind turbines is considered as a convex polygon. This polygon constitutes the object whose visual occupation is to be estimated. The considered area for the horizon surface occupation is the one derived by the polygon projection on a perpendicular sight direction plan located at one meter of the observer. The sight is supposed in the direction of the farm center. The apparent height of the turbine is derived from the actual hub height which a hidden part has been removed due to the Earth curve when the turbines are located above the horizon distance. The surface occupied by the farm on the horizon is defined by the area delimited by a convex curve joining the turbine hubs placed at the polygon visible edges.

### *2.2. Distinguishable turbines*

Two reasons for not seeing turbines are often considered, both taken in the case of perfect condition visibility. The first one is that the turbine dimensions are too small to be perceived at a given distance. The second one depends on the way which side-by-side turbines can be distinguished according to the observer point of view and its direction sight. The notion of visual acuity should be also considered. The angular visibility of the human vision is a parameter which is used to determine if the projection of two turbines or more in the same plane can be considered as one (or a group of innumerable turbines). The results depend on the turbines distance and the tower diameter dimension. The minimum object size that a person with a normal visual acuity is able to recognize is one arc minute [13]. If the gap between the turbines is less than the minimal distance needed to differentiate them, then the farthest turbine is not taken into account. The turbine indicator, *TI* is defined as the ratio between the number of distinguishable turbines and the total number of turbines, *TI=Distinguishable turbines / Total turbines number*.

### *2.3. Aesthetic indicator*

The continuity and fractal dimension has been introduced to describe the aesthetic notion of an offshore farm [14]. Here, the approach is mostly oriented towards regular grid turbines, the number of turbine arrangements that can be clearly distinguished is taken into account. The aesthetic indicator implies, according to view angle of the observer, to enumerate the number of turbine arrangements that can be clearly dissociated (i.e., not overlaid by other turbines alignments in the projection). The turbine spatial arrangements are composed by the different alignments exhibited by the turbine layout. In a regular grid configuration observed perpendicularly, these turbines are observed as rows, or as diagonals in other cases.

The aesthetic parameter (AI) is defined as the ratio between the number of turbine alignments that can be practically distinguished and the maximal number of alignments that can be theoretically observed, $AI=Alignement_{seen}/Alignments_{Total}$ . The aesthetic indicator is linearly scaled from 0.5 to 1.5. An optimal aesthetic arrangement with regular and harmonious turbines arrangements is supposed to reduce the impact, a visual aesthetic indicator of 0.5 is valued in this best case. On the contrary, a chaotic distribution is supposed to decrease the visual acceptance, a valuation of the visual impact of 1.5 is chosen for that worst case.

## 3. Experimental validation

In order to illustrate the approach we consider the case of an offshore wind farm project located in Saint-Nazaire in North West France (Fig. 1). The turbine towers of 80 meters high and 4 meters large are considered. The assessment of the visual impact is carried out for 12 observation points located around the farm and in the seacoast.

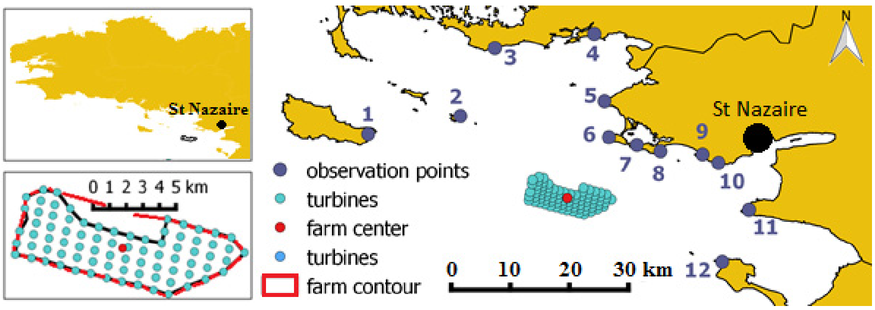


Fig. 1. Offshore wind farm layout projected in the Saint-Nazaire region

The first step of the approach is to consider the wind farm projection on a plane perpendicular at the sight direction. Fig. 2 shows the apparent hub height and the turbines arrangement for an observer located at different locations. The horizon occupation, *HO*, is defined as the surface below the curve enveloping the turbine hubs. The second step consists in the evaluation of the distinguishable turbines, turbines that are too far or too close from other turbines to be distinguished are not taken into account.

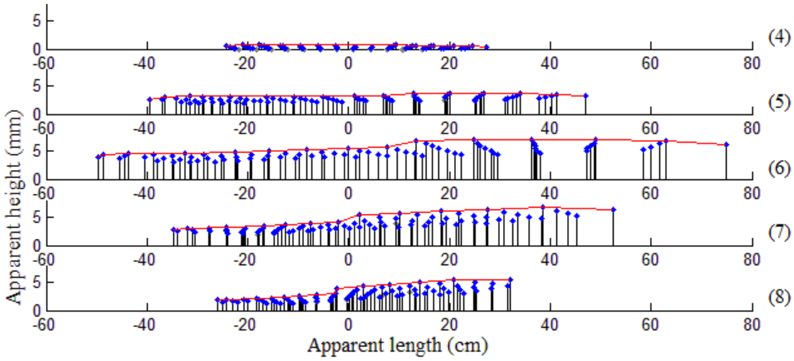


Fig. 2. Visualization of hub height projection for the observation points from 4 to8

Fig. 3 shows the possible turbine alignments that can be observed regarding the St-Nazaire wind farm layout. Considering the regular grid layout composed by L rows and C columns, the third step is to identify the different alignments (also diagonals) that can be dissociated. The ratio between the identified alignments and maximal number of alignments is calculated. The maximal number of alignments is given by either the maximal number of columns (e.g., 15 as illustrated by Fig. 3), the maximal number of rows (e.g., 7 as illustrated by Fig. 3) or the maximal number of diagonals (i.e., 16 or 20 as illustrated by Fig. 3) depending on the observer point of view. In other words a person rather located in the front view is more likely to perceive the 'column' alignment. In the case illustrated by Fig. 3, the maximal number of alignment is the one given by the number of columns.

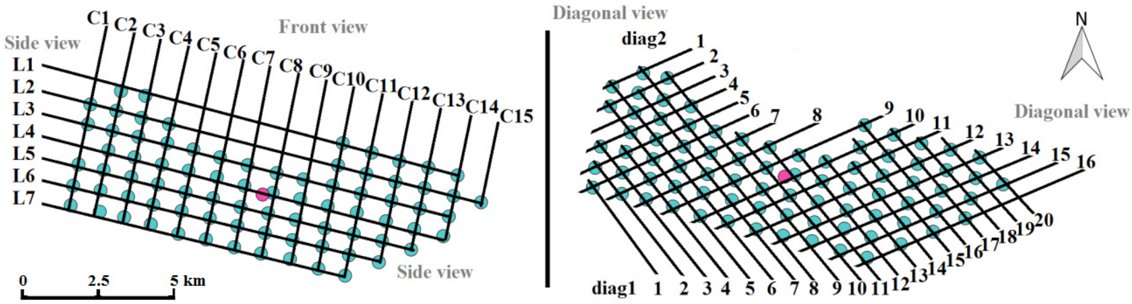


Fig. 3. Wind farm layout and alignments visualization, 'L' row alignments, 'C' column alignments, 'diag' diagonal alignments

The results derived for the different indicators are summarized in Table 1. Details of the aesthetic indicator estimation are also given in the table and provide information on which turbine alignments can be discerned.

In particular, it appears that for the observation point 6, the turbine arrangements that can be observed came from two different types of alignments (diagonal and column). At this point, the maximal number of arrangements that can be seen theoretically is 15, the observer is then considered in the front area of the wind farm. At the observation point 1, the number of turbines seen is too low to consider the calculation of the aesthetic indicator, it is therefore not taken into account in the evaluation of the visual impact. The visual impact operator is defined as the cross product of the different indicators:

$$\mathit{Visual\ Impact} = HO \times TI \times AI$$

where *HO* denotes the horizon occupation, *TI*, the turbine indicator and *AI* the aesthetic indicator

Table 1. Experimental results for the different indicators

| Observation points | HO ($cm^2$) | Distinguishable turbines (/80) | Aesthetic factor (AI) | Number of alignments seen | Alignments affected[1] | | Alignments total[2] |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 5 | / | Details of aesthetic indicator evaluation | | | |
| 2 | 9.2 | 77 | 1.3 | 4 | diag1 | 1, 2, 3, 4 | 20 |
| 3 | 2.9 | 53 | 1.1 | 8 | diag1 | 11 to 18 | 20 |
| 4 | 3.4 | 65 | 0.5 | 15 | C | 1 to 15 | 15 |
| 5 | 28.7 | 76 | 0.83 | 10 | C | 6 to 15 | 15 |
| 6 | 73.9 | 80 | 0.97 | 5+3 | C<br>diag2 | 11 to 15<br>1,2,3 | 15 |
| 7 | 44.4 | 78 | 1.06 | 7 | diag2 | 1 to 7 | 16 |
| 8 | 22.5 | 76 | 0.94 | 9 | diag2 | 1 to 9 | 16 |
| 9 | 6.3 | 72 | 0.94 | 9 | diag2 | 3,4,5<br>11 to 16 | 16 |
| 10 | 3.7 | 55 | 1 | 8 | diag2 | 4 to 8<br>14 to 16 | 16 |
| 11 | 1.4 | 31 | 1.5 | (1) row, column, diagonal numbers that can be distinguished | | | |
| 12 | 2.9 | 44 | 1.5 | (2) maximal number of alignments that can be seen theoretically | | | |

The results for the offshore wind farm of Saint-Nazaire at the different observation points are summarized in Fig 4. The figures that appear confirm that the distance of the farm to the observation point is an important factor in the visual assessment. However, it also appears that the results exhibited show different aesthetic trends. For instance at the observer point 3, the visual impact is less important than at the observation point 4 according only to the horizon occupation indicator.

Although variations in the results may come from the way the aesthetic coefficient has been rescaled. For a better valuation and understanding of this measure, a complementary study that will evaluate how much the aesthetic indicator influences the visual impact, and therefore the degree of acceptance should be performed. Indeed, this visual impact estimation method should be integrated as part of a more complete decision-aid tool oriented to marine renewable energy project planning. It should be used at an early planning stage to compare the visual impact of several farm projects.

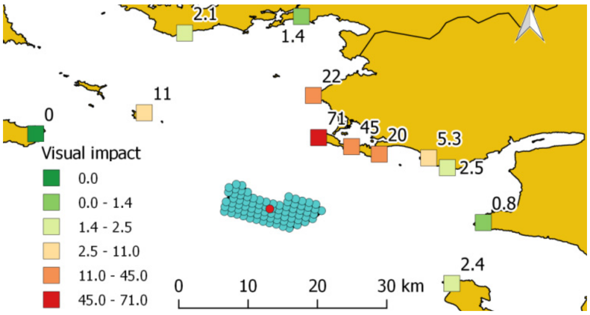


Fig. 4. Visual impacts of the offshore wind farm

## 4. Conclusions

The research developed in this paper introduces a computational-based operator for quantifying the visual assessment of an offshore wind farm. This operator is designed as an intelligible and objective function, and can be used in several iterations to estimate the visual impact of different farm projects. This approach also includes a new method for measuring the aesthetic of an offshore wind farm.

The work is preliminary and should be extended to include for instance some additional parameters such as the real density of population land uses closely related to the observation points as defined by the current approach. Accordingly, the seacoast might be segmented into different observation areas. An aggregation of the different variables identified using a multicriteria analysis is another relevant direction to explore in order to match as much as possible decision-making processes, and an appropriate level of subjectivity in the final step of the decision process.

## References

[1] Horn M, Krupp F. *Earth: The sequel: The race to reinvent energy and stop global warming*. WW Norton & Company; 2009

[2] Jeffrey H, Jay B, Winskel M. Accelerating the development of marine energy: Exploring the prospects, benefits and challenges. *Technological Forecasting and Social Change* 2013;**80**:1306–1316.

[3] Brown MT, Cohen MJ, Sweeney S. Predicting national sustainability: the convergence of energetic, economic and environmental realities. *Ecological Modelling* 2009;**220**:3424–3438.

[4] Douvere, Fanny. The importance of marine spatial planning in advancing ecosystem-based sea use management. *Marine policy* 2008;**32**:762–771.

[5] Gill AB. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. *Journal of Applied Ecology* 2005; **42**:605–615.

[6] Boehlert GW, Andrew BG. Environmental and ecological effects of ocean renewable energy development: a current synthesis. Journal of The Oveanography Society 2010;**23**:68–81.

[7] Sullivan RG, Kirchler LB, Cothren J, Winters SL. Offshore Wind Turbine Visibility and Visual Impact Threshold Distances. *Environmental Practice* 2013;**15**:33–49.

[8] Barrow CJ. *Environmental impact assessment: Cutting edge for the twenty-first century*. A. Gilpin. Cambgidge: Cambridge university press; 1995.

[9] Bishop ID. What do we really know? A meta-analysis of studies into public responses to wind energy. In *World Renewable Energy Congress,* Linköping University Electronic Press, Linköping, Sweden; 2011, p. 4161–4169.

[10] Ladenburg J. *Visual impact assessment of offshore wind farms and prior experience*. Applied Energy 2009;**86**:380-387.

[11] Molnarova K, et al. *Visual preferences for wind turbines: Location, numbers and respondent characteristics*. Applied Energy 2012; **92**: 269–278.

[12] Paar P. *Landscape visualizations: Applications and requirements of 3D visualization software for environmental planning*. *Computers, environment and urban systems* 2006;**30**:815–839.

[13] Shang H, Bishop ID. *Visual thresholds for detection, recognition and visual impact in landscape settings*. Journal of environmental psychology 2000;**20**:125–140.

[14] Sibille ADCT, Cloquell-Ballester VA, Cloquell-Ballester VA, Darton R. *Development and validation of a multicriteria indicator for the assessment of objective aesthetic impact of wind farms*. Renewable and Sustainable Energy Reviews 2009;**13**:40–66.

### Biographies

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