Energy Policy 113 (2018) 53–67

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

# Developing offshore wind farm siting criteria by using an international Delphi method

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ARTICLE INFO

*Keywords:*
Offshore wind farm
Siting criteria
Ocean conflicts
Marine renewable energy
Marine Spatial Planning
Delphi method

ABSTRACT

Previous research on offshore wind farm (OWF) siting has been dominated by studies centred on energy resources and profitability, human activities and acceptance. Recently, studies on environmental impacts of OWFs have emerged. Few studies have been carried out to discuss the issues comprehensively. This study develops a set of comprehensive OWF siting criteria; including the profitability, social, security and environmental considerations. It solicits expert opinions from academia and industry through an international Delphi method. Contrary to the typical consensus seeking in Delphi studies, it focuses on understanding the dissensus through a comprehensive discussion. We find that profitability and social considerations are the most commonly agreed siting criteria among the experts whereas environmental and security criteria receive less agreement. As OWFs move further offshore, we are concerned about the understanding of the associated environmental impacts, and how energy and marine policy affect the marine spatial planning and consenting process. Research must get ahead of the developments to provide a better understanding of the potential impacts and to guide the consenting and monitoring processes.

## 1. Introduction

The first offshore wind farm (OWF) in the world was made operational in Vindeby, northwest of Lolland in the Baltic Sea, in September 1991 (Danish Energy Authority, 2005). The development process provides invaluable experience to Denmark, particularly in considering the factors related to wind energy variability, OWF siting and investment. Above all, the conflict of OWF visibility from the shore was the main consideration. In addition, the Danish environmental authorities had to consider the conflicts between the OWF and sailing activities, fishery, nature values, wildlife, offshore drilling, telecommunications, air traffic and military interests. The conflicts have critically minimised the area suitable for an OWF development (Meyer, 1995). Initially, the industry and policy-makers, even some academics thought developing offshore wind energy was an easy way out from the problems of establishing onshore wind capacity. The idea was far too simple (Wolsink, 2010). Denmark is not alone; today many countries face ever increasing constraints in assessing suitable sites for offshore wind development. Research on OWF siting has improved our understanding of the factors affecting offshore wind investment and acceptance. So far, numerous factors have been identified; including marine spatial planning (Bishop and Stock, 2010; Gimpel et al., 2015; Griffin et al., 2015; Jay, 2010; Möller, 2011; Punt et al., 2009), social (Aitken, 2010; Bell et al., 2005; Bishop and Miller, 2007; Brownlee et al., 2015; Firestone et al., 2012; Firestone and Kempton, 2007; Gee, 2010; Haggett, 2011, 2008; Ho, 2016; Iglesias et al., 2011; Karlstrøm and Ryghaug, 2014; Ladenburg, 2009, 2008; Ladenburg and Dubgaard, 2007; Landry et al., 2012; Nadai, 2007; Prados, 2010; Westerberg et al., 2013, 2012; Wolsink, 2010), profitability (Gao et al., 2015; Levitt et al., 2011; Lumbreras and Ramos, 2013; Réthoré et al., 2014; Snyder and Kaiser, 2009a, 2009b), birds (Furness et al., 2013; Kikuchi, 2008; Marques et al., 2014) and bats (Kunz et al., 2007) collision, marine environment (Bailey et al., 2014, 2010; The Scottish Government, 2010; van der Molen et al., 2014; Wilding, 2014) and others (Jongbloed et al., 2014; Kim et al., 2016; Lindgren et al., 2013; Portman et al., 2009; Richards et al., 2012; Santora et al., 2004; Söderholm et al., 2007). Much of this work focuses on individual or a mix of multiple factors, but few studies have been carried out to include a comprehensive list of OWF siting criteria, except (Kim et al., 2016). The conventional academic training emphasising a discrete disciplinary focus such as engineering, marine biology and ecology, sociology, tourism, military studies, etc. may inhibit the comprehensive and interdisciplinary understanding of a multi-faceted subject such as OWF siting.

At the same time, previous research on OWF siting has been

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http://dx.doi.org/10.1016/j.enpol.2017.10.049
Received 11 May 2017; Received in revised form 21 August 2017; Accepted 27 October 2017
Available online 21 November 2017

dominated by studies centred on energy resources and profitability, human activities [Refer Table 1 in (Kim et al., 2016)] and acceptance (Refer Table 1). The general worldview that environment is a commodity that is tradable with other opportunities presents risks to the marine environment with regards to OWF siting. While offshore wind energy may help combat global warming, it is not a panacea for the ever increasing onshore energy demand problems; OWF may add stress to already crowded marine ecosystems in addition to other anthropogenic uses. Recently, studies concerned about the environmental impact of offshore wind energy have emerged (Franco et al., 2015; Grilli and Shumchenia, 2015; Kaldellis et al., 2016; Masden et al., 2015; Mroziński and Piasecka, 2015; Raoux et al., 2017; Smyth et al., 2015; Verfuss et al., 2016; Yates et al., 2015). Hence, it is important to have sound marine and energy policies translated into good marine spatial planning practices in balancing the OWF siting factors and finding suitable OWF sites. The study (Kim et al., 2016) on OWF site selection has identified a set of siting criteria from the literature. While it has improved our understanding of the application of OWF siting criteria in selecting suitable sites, it was based on eight research articles published in 2012 or earlier; each presented a different set of criteria. Furthermore, the multifaceted and interdisciplinary nature of OWF siting demands a comprehensive understanding and consideration of the OWF siting criteria, in addition to applying the siting criteria. It is imperative that energy studies become more interdisciplinary and heterogeneous in trying to understand the uptake of technologies (Sovacool, 2014). The advancement of policy makers' comprehensive and interdisciplinary understanding of the siting criteria is fundamental and crucial for the formulation of sound marine and energy policies that will directly influence the nature of OWF siting, offshore wind energy investment, social acceptance and most importantly the sustainability of our marine environment and eco-systems.

The current study aims to develop a set of comprehensive OWF siting criteria. Using an international Delphi method, the study validates a set of OWF siting criteria identified from the literature up to April 2014 and develops a set of additional OWF siting criteria. In 2014, 15 experts (refer to the acknowledgement section) from ten different countries and with a variety of expertise and discipline, sufficiently representing the groups of subjects being studied, completed this survey. The survey was conducted through email using Microsoft EXCEL files. This was thought to be the quickest and most cost-effective way to gather opinions from a group of international experts. Section 2 of this paper describes the Delphi method used. We identify the consensus and dissensus on the importance of OWF siting criteria from two Delphi rounds. In Section 3, we discuss the results and OWF siting criteria based on a measure of the spread of expert responses and recent literature, which lead to the rigorous and thought-provoking discussion in this paper. The conclusions and policy implications are presented in Section 4.

## 2. Methodology

The term 'Delphi method' originated from the Oracle of Delphi in ancient Greece, which was consulted on matters that ranged from personal affairs to public policy (Steurer, 2011). Since its development by the RAND Corporation in the early 1950s (Orsi et al., 2011) and its introduction in 1975, it has been progressively received and used by academics (Rowe and Wright, 2011), and widely used to solicit input from a group of experts (Diamond et al., 2014). The main advantages of the Delphi method are the ease of communication by international experts through electronic means, and the anonymous response format that allows experts to state their preferences without being dominated by other experts. However, Delphi method is criticised due to its reliance on expert judgement, which may relate to the personal point of views and beliefs. In contrast, the expert judgement is useful when scientific evidence is either contradictory or not available. In such a situation, the collective expert opinions may be more trustworthy than that of one expert. Therefore, one of the most crucial aspects of the Delphi survey is the selection of qualified experts. Nevertheless, there are no specified rules regarding the number of participants and the selection of participants (Steurer, 2011). Ref. (Rowe and Wright, 2011) provides a wide variety of perspectives on the Delphi method.

There are three main parts of a Delphi survey: The first part refers to identifying and explaining the subject of study, and preparing the appropriate questionnaire; second, identifying and selection of a panel of participating experts; and lastly, sorting out and running the survey, which normally involves two or more rounds. The iteration of rounds is a key aspect of the Delphi method to identify the convergence or divergence of views, though the achieving of consensus is typically sought after. Interestingly, often, thought-provoking and crucial discussions appear in the absence of consensus (Rowe and Wright, 2011).

### 2.1. Subject of study

Table 1 shows the OWF siting criteria identified from the published literature up to April 2014. The criteria include profitability, social, security and environmental concerns which are measurable by location and distance. Criteria that are not location and distance-based were not part of the study and therefore were not included in the Delphi survey.

### 2.2. Participants

In 2014, 42 international experts were invited to participate in the current Delphi survey. The experts were identified from publications related to OWF siting issues; reputable international organisations directly related to OWF siting; industry experts; local governmental and NGOs. Unfortunately, OWF developers are typically reluctant to share their technical knowledge (Möller, 2011) especially in terms of locating the specific OWF sites. Twenty-five out of the 42 experts responded. The experts were asked to self-rank their expertise level related to either (one or more) offshore environmental study, environmental impact assessment, related projects on offshore or ocean climate, sensitive area, ecology & biodiversity, and pollution; economic study or related projects on OWF, marine engineering and other marine economic activities; social study, Social Impact Assessment or related projects on visual or psychological impact from offshore wind turbines including local acceptance, tourism as well as employment; security study, security risk assessment or related projects on maritime border safety & risk, naval and aviation risk from wind turbines or other objects. The experts ranked their expertise level for each group of study areas from expert, knowledgeable, familiar to unfamiliar. According to (Rowe and Wright, 2011), self-rated experts tend to persevere through the rounds compared to those who rated themselves as less-expert. Two invitees who did not rank themselves as expert or knowledgeable in any of the mentioned field of studies were dropped from the survey.

### 2.3. Likert scale

The perceived importance of OWF siting criteria affects the attention and consideration given to it in the policy making and the actual OWF siting decision-making. During the Delphi rounds, the experts ranked the importance of the OWF siting criteria on a 5-point Likert scale from unimportant, somewhat important, important, very important, to extremely important.

### 2.4. Stopping the Delphi survey

Many researchers have used consensus measurement as a sole stopping criterion of Delphi rounds. This is not recommended. Instead, we agree with the discussion in (von der Gracht, 2012) that consensus is only meaningful if group stability has been reached beforehand. Stability is defined as the consistency of responses between successive rounds of a study; the results of two different Delphi rounds are not