Marine Policy 81 (2017) 359–367

Contents lists available at ScienceDirect

Marine Policy

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

Exploring the implications of tidal farms deployment for wetland-birds habitats in a highly protected estuary

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ARTICLE INFO

Keywords:
Tidal energy
Intertidal habitats
Waterfowl
European Marine Site
Numerical model

ABSTRACT

Next generation turbines can be installed to exploit tidal energy resource in estuaries. However, the ecological implications of such deployments remain unknown. Accordingly, this study is focused on the impact of tidal farms on intertidal areas and associated waterbird habitats in estuaries. A numerical model simulates the hydrodynamic conditions of the Solway Firth, comprising one of the most extensive intertidal zones in the UK. The effects of tidal farms with different turbine densities have been evaluated in terms of changes to the areas of habitat for wetland bird species of conservation importance. The results suggest that any habitat loss may be minor and that in some cases there may be an increase (also small) in the area of important habitat. The percentage change in intertidal areas is also considerably lower than that expected to result from tidal barrages of similar capacities, implying the potential for tidal farms to present an alternative solution for exploiting tidal energy in highly protected areas. The changes in the extent of intertidal habitat are not proportional to the energy dissipated by the tidal farm. Therefore a range of tidal farm designs should be evaluated in order to optimise installed capacity while minimising habitat loss. However, the site-dependency of the impacts and the complex responses to change of estuarine ecosystems reinforce the requirement for detailed studies to be undertaken for each specific location and array configuration. The methodology presented here is appropriate for such assessments as it can be applied to different locations and turbine types.

1. Introduction

Marine renewable energy schemes could provide up to 20% of the UK electricity demand [1] and help to reduce carbon dioxide emissions, becoming an alternative to traditional generation systems. However, it is necessary to evaluate the environmental impacts of such technologies as developers must gain consent from the relevant regulators, thus affecting the pace of deployment of these systems at a commercial scale. Masden et al. [2] highlight the delays in the consenting process for offshore wind farms in the UK caused by uncertainties in relation to impacts on birds, and the broadly positive evaluation of the economic case for UK tidal lagoons [3] has led to calls for the proposals for multiple lagoons to be halted until the environmental consequences of a single pilot installation have been thoroughly evaluated [4].

Tidal impoundment structures such as lagoons, and previously tidal barrages, have been the focus of attempts to exploit the energy of macro-tidal estuaries, but significant concerns remain about the implications of changes in water levels for estuarine intertidal habitats such as salt-marshes and mudflats. These habitats are particularly important for birdlife [5], and negative impacts on them have the potential to be pivotal to planning decisions given the high level of protection of many estuaries under the European Habitats and Birds Directives [6,7].

In relation to the impacts of tidal barrages on waterbirds habitats, Charlier [8] indicated that the reduction of tidal range due to the barrages would reduce the size of mudflats and marshes, affecting the reproduction of migratory birds. The negative effects of increased submersion of bird feeding areas have been also highlighted by Frid et al. [9], and the increased mortality of birds displaced due to loss of intertidal habitats has been observed by Burton et al. [10]. Changes to tidal excursions and coastal processes may also affect shorebird foraging [11] and, according to the analysis carried out by Morris [12] by means of conceptual models of barrages, changes on sediments composition would have a higher impact on migratory birds than expected. Such concerns about the environmental impacts of tidal barrages have remained a significant factor in their continued rejection by the UK Government [13,14].

Given that high current speeds will generally occur in locations with

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http://dx.doi.org/10.1016/j.marpol.2017.04.011
Received 31 January 2017; Received in revised form 10 April 2017; Accepted 11 April 2017
Available online 25 April 2017

high tidal ranges, arrays of tidal current turbines (tidal farms) could be suggested as an alternative to impoundment structures in estuaries. Although previous feasibility studies of tidal power schemes in, for example, the Severn estuary [13] have rejected tidal farm options, these studies only considered axial flow turbines more suitable for deep areas, and their conclusions do not reflect recent developments in tidal current technologies. Examples of devices which can be effectively deployed in shallower waters include the Kepler Energy transverse horizontal axis water turbine (THAWT) [15], Edinburgh vertical axis cross-flow turbine [16], Gorlov helical turbine [17], Aquascientific momentum reversal lift (MRL) turbine [18], and cross-flow designs [19]. Nevertheless, it is necessary to bear in mind that, in order to be commercially competitive, these farms would consist of a large number of devices and it remains necessary to understand the environmental changes derived from the intra-array effects at basin scales [20].

Areas of concern with regard to the environmental impact of tidal current devices have been identified as flow alteration, changes to sediment and nutrient transport, flushing characteristics, habitat disturbance, electromagnetic fields, noise, and risks of collision and pollution [21,22]. Due to the lack of installed tidal current devices, the use of models which replicate the physical trends and conditions in the potential locations is common practice in attempting to understand the implications of such devices. Some examples of the use of numerical models to assess the hydrodynamic impacts of tidal farms in estuaries can be found in the studies carried out by Sánchez et al. [23] for the Ria de Ortigueira (NW Spain) or Ahmadian et al. [24] for the Severn estuary.

Specific studies to model the impact of tidal farms on intertidal habitat loss in estuaries are rare, however, but suggest the potential for considerable change. Nash et al. [21] show that up to 25% of intertidal habitat could become permanently submerged at high turbine density in the Shannon estuary. Therefore, although the impacts of turbine arrays on the tidal range are expected to be minor compared to the effects of tidal impoundment structures, the consequences derived from those changes on intertidal areas should not be neglected and requires detailed analysis in more detail. As remarked by Uihlein and Magagna [25] it is necessary to integrate environmental constraints, such as protected habitats, at the stage of resource assessment.

Given our lack of understanding of the potential environmental impacts of large-scale tidal arrays and the importance of the protected species in estuaries of interest to tidal energy development, this study will focus on the potential change in distribution of intertidal and subtidal areas within an estuary and the likely implications of this for the availability of suitable habitat for wetland birds and waterfowl. For that purpose, this novel study presents a generic methodology demonstrated by a numerical model of a real case study in the Solway Firth, UK, to evaluate multiple scenarios of tidal farm developments. Although the impacts are site specific and the results of this study cannot be generalised to other locations, the methodology here presented can be applied to any other projects. It intends to provide a support tool at the initial stages of design of the turbine farms during the decision making process.

2. Methods

2.1. Case study selection

Based on the group of estuaries suitable for tidal energy extraction in the UK identified by Garcia-Oliva et al. [26] and the presence of substantial intertidal areas, the Solway Firth has been selected as a representative case for the analysis of the impact of tidal farms on intertidal habitats. Fig. 1 shows the location of the estuary on the border of England and Scotland, between Cumbria and Dumfries and Galloway. Spring velocities in the Solway Firth are of the order of 2 m/s at some locations and it is one of the best examples in Europe of a large estuary with significant natural habitats [27,28].

The environmental importance of the estuary lies in the fact that it is the third largest area of continuous mudflats and sandflats in the UK and that it is not substantially affected by human activities [29]. It holds the status of a European Marine Site (EMS), which consists both of a Special Area of Conservation under the EC Habitats Directive and a Special Protection Area under the Birds Directive [29]. It is also designated as a Ramsar Wetland and contains Sites of Special Scientific Interest [30]. Water birds of global relevance feed in the intertidal mudflats and sandflats at the inner part of the estuary [27], and support associated leisure and tourist activities such as bird-watching.

2.2. Numerical model

For the purpose of this study, a numerical model of the Solway Firth estuary has been developed by means of Mike21 (by DHI), a commercial software which has been extensively used for coastal applications in both industrial and academic environments. A summary of the modelling approach is presented below, for further details see the Supplementary material.

The model domain was created by means of several datasets from different sources, and the extension of the domain was large enough to avoid a reflection of the wave from the tidal farm at the boundary. Regarding the treatment of moving boundaries, a wetting depth, a flooding water depth and a drying water depth can be defined within the model. The model also includes the equations for temperature, salinity and density as well as a turbulence closure scheme. The validation of the model was performed by comparing model outputs with published water levels.

The tidal turbines were modelled as sub-grid structures by reducing the flow velocity due to an additional resistance which increases with the flow speed. The effect of turbines was introduced in the governing equations as an additional shear stress component from the drag force imposed to the flow, in a similar way to the wind or radiation stress components. Mike21 includes a correction to avoid reduced flow velocity effects in finer meshes. A sensitivity analysis of the mesh size showed that a maximum element size of the order of 1 km^2 would not introduce a significant error in the results, reaching a good compromise between the resolution and the computational time of the simulations. More details about the simulation features and turbine design can be found in the Supplementary material.

In order to identify the potential locations of the tidal farms, the maximum speed of the currents and minimum water depths were calculated during the period of the validation of the model. It was considered that velocities over 1 m/s are more desirable for energy extraction and that minimum water depths of 7 m would provide enough clearance for a chosen turbine diameter of 5 m. Fig. 2 shows a combination of both requirements and other constraints. Two locations have been identified for the tidal farms, represented by rectangles, covering the regions with the highest current speeds where possible. The tidal farms in the model have been defined by several rows of turbines. The longitudinal axis of the farm is parallel to the main current direction, which has been calculated as the average between the current directions during the mid-flood and mid-ebb spring and neap tides at points A and B (Fig. 2).

Three tidal farm cases were simulated: Case A (958 turbines, 240 MW installed capacity); Case B (2166 turbines, 542 MW); Case C (8664 turbines, 2.2 GW), to represent energy generation capacities comparable to tidal range options that were suggested during a feasibility study for tidal energy in the Solway Firth (Halcrow Group et al. [28]). Case C presents an unrealistically high number of turbines and is included as a means of evaluating a potential ‘worst cast’ scenario.

The results of water levels were obtained for the period of the simulations in the cases without turbines and with the three different sizes of tidal farms. Only the second half of the simulation was considered for the analysis of the results because the warm-up period