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Assessment of the energy extraction potential at tidal sites around the Channel Islands

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ABSTRACT

Tidal flows around the Channel Islands contain a significant energy resource that if harnessed could provide electrical power to the Channel Islands, the UK and France. We have developed a new 2D hydrodynamic model of the English Channel which gives an improvement to the temporal and spatial resolution of the ambient flow in comparison with previous regional scale resource assessments. The ambient flow was characterised to identify suitable sites, resulting in a reduction in total development area of up to 80% compared with previous studies. Estimates for upper bound energy extraction confirm that Alderney Race contains the majority of the Channel Islands resource, giving a maximum potential of 5.1 GW, which exceeds a previous estimate for the Pentland Firth by 35%. This is followed by Casquets (0.47 GW) and then Big Roussel (0.24 GW). Our work shows that energy extraction at Alderney Race has a constructive impact on the resource at Casquets, and that the sensitivity to added drag at each site with respect to energy extraction is highly dependent on bathymetry and the proximity of coastlines. These results have implications for the overall resource development within the Channel Islands, where regulation is needed to account for site-site interaction.

1. Introduction

The Channel Islands are a collection of five main islands located to the west of the Cotenin Peninsula in Normandy, France (Fig. 1). In reports commissioned by the Carbon Trust [1,2] five sites were identified as suitable for tidal energy development based on tidal current velocities (mean neap peak and mean spring peak velocities), bathymetry and available area. These include three main sites of medium to high potential (Alderney Race, Casquets and Big Roussel) and two low potential sites off the North West coast of Guernsey and off the North East coast of Jersey.

Estimates for energy extraction at these sites vary significantly depending on the method used and the scheme areas and array design considered. This is demonstrated in Table 1, which summarises the range of results from previous assessments of Alderney Race, Casquets and Big Roussel. In general, past studies have relied on low spatial and temporal resolution flow data, which may have impacted on the derived results. Additionally methods such as the farm and kinetic flux approaches adopted in the past [3,4,2] assume no change to the ambient flow field with the inclusion of turbines (i.e. no consideration into blockage effects), bringing into question the validity of these results. Other studies assume a 5% wake deficit within turbine arrays [5], yet they still do not consider the array scale blockage caused by the considerable added drag by large arrays. For further information on the farm and kinetic flux methods we recommend the reader consults the references given in Table 1.

We recognise that previous studies have provided a knowledge enhancement for assessing the tidal energy resource at sites within the Channel Islands. However, the varied approach to site characterisation, energy extraction model and scarcity of reliable flow data makes it difficult to make direct comparisons of the resource at each location. To address this problem a well-established method for quantifying an upper bound for power extraction (termed the maximum average power potential) was implemented here for sites in the Channel Islands using a new 2D hydrodynamic model of the English Channel. The method is described below and in more detail in §2.4, and is the same approach as has been conducted in literature to estimate the maximum average power potential of the

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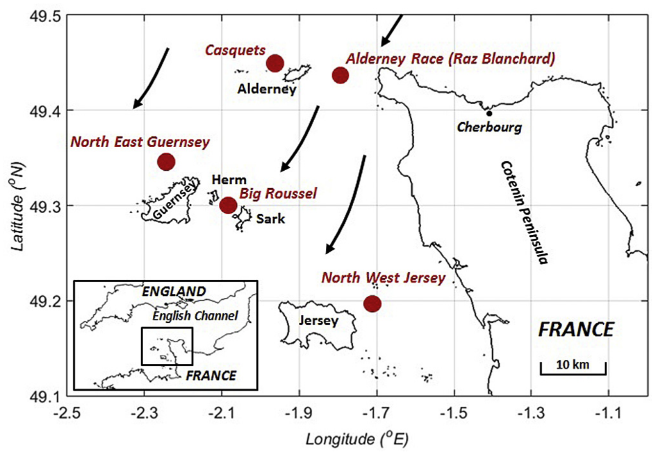

Fig. 1. Location of potential sites for tidal energy development in the Channel Islands [1], located off the west coast of Normandy, France. Arrows show the direction of dominant ebb tide. The relative location of the Channel Islands to the UK and France is shown inset.

Pentland Firth in Scotland [6] and Minas Passage [7,8], Johnstone Strait [9] and Masset Sound [10] in Canada.

Within the hydrodynamic model, a drag is distributed uniformly over 'energy extraction zones' that span the entire width of a site. This is done to simulate momentum extraction by large tidal stream turbine arrays. The total power extracted from the flow by the added drag within the energy extraction zone is calculated and averaged over time to give an 'average power potential'. This is not to be confused with the *available* power, which is the fraction of the extracted power that is removed by the turbines (which is used directly for electricity generation) [6]. To simulate the effect of adding more turbines, the drag distributed over the energy extraction zone is increased, resulting in an increase in the hydrostatic pressure force driving the flow through the zone, seen as an increase in the difference between free surface elevation upstream and downstream of the energy extraction zone. This added drag reduces the volume flux through the energy extraction zone. Assuming alternative flow paths exist, the increase in hydraulic resistance caused by the added drag also causes flow to divert around the energy extraction zone, taking the path of least resistance. The extracted power within the energy extraction zone is the product of the head loss across the energy extraction zone and the volume flux through the energy extraction zone. Initially, as drag is added there is an increase in the head drop across the energy extraction zone, which has a dominating effect over the decrease in volume flux, causing the extracted power to increase. As the uniformly distributed drag is increased further, the reduction in volume flux has an increasingly significant effect over the increase in head drop, where at the upper bound it suppresses the increase in head drop, initiating a decrease in the extracted power. The maximum average power potential is the upper bound limit of the average power potential. It is the maximum power that can be extracted by adding a uniform drag over the energy extraction zone, where any further increase in drag causes a reduction in the extracted power.

The information in the paper is organised as follows: in §2 a new 2D hydrodynamic model of the English Channel is presented, which simulates flow around the Channel Islands at significantly improved spatial and temporal resolution compared with previous regional scale studies summarised in Table 1. Model validation results are presented in §3 using elevation data at 13 ports around the domain, as well as flow data obtained from Acoustic Wave and Current Profiler (AWAC) deployments in Alderney Race. Such combination of validation datasets gives confidence in the model's ability to accurately recreate tidal flows around the Channel Islands. Ambient flow distribution results are presented in §4.1, which were used to quantify the distribution in mean kinetic power density at Alderney Race, Casquets, Big Roussel, North West Guernsey and North East Jersey. In §4.2 estimates for the power potential at suitable sites are given, and comparisons are made with estimates for the maximum average power potential at the Pentland Firth in Scotland [6], Minas Passage [7,8], Johnstone Strait [9] and Masset Sound [10] in Canada (Table 6). In §4.3 the level of interaction between each site is investigated by simulating simultaneous energy extraction scenarios. This is novel as it is the first time site-site interaction has been quantified for sites around the Channel Islands. In §4.4 results are presented that consider more realistic levels of array drag based on the physical constraints of turbine spacing. Power extraction from these more realistic simulations are compared with the upper bound solutions from §4.2 and §4.3 to comment on the possible level of tidal energy development at each site. In §4.5 the available power is estimated by implementing the realistic level of drag at each site. The available power is defined as the fraction of the extracted power that is removed by ideal tidal turbines for electrical power production [6]. In §4.6 the effect of added drag on the surrounding flow field is plotted and the change in volume flux through each site is quantified.

Table 1
Results from literature showing methods used, array capacity and electricity generation from Alderney Race, Casquets and Big Roussel.

Method	Studies	Array scheme area or cross section	Array capacity (GW)	Annual electricity generation (TWh/year)
Alderney Race				
Farm	ETSU [3], European Commission [4], Bahaj et al. [10], Myers et al. [11]	65 km^2–102 km^2	0.84–2.4	1.35–7.4
Kinetic energy flux	Black and Veatch, Phase I [2], Black and Veatch, Phase II [2], Owen [11]	3.3 km–5.5 km wide cross sections	NA	0.37–1.37
Power potential	Black and Veatch, Phase III [12]	5 km wide cross section	NA	2.25
Casquets				
Farm	ETSU [3], European Commission [4]	190 km^2–215 km^2	0.37–2.5	1.3–2.9
Kinetic energy flux	Black and Veatch, Phase I [2], Black and Veatch, Phase II [2], Owen [11]	8 km wide cross section	NA	0.4–1.6
Power potential	Black and Veatch, Phase III [12]	61 km^2	NA	1.9
Big Roussel				
Farm	ETSU [3]	90 km^2	2.5	2
Kinetic energy flux	Black and Veatch, Phase I [2], Owen [11]	2.7–4 km wide cross section	NA	0.16–0.3