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FUTURE SCENARIOS AND POWER GENERATION OF MARINE ENERGY DEPLOYMENT AROUND GREAT BRITAIN

Iain A. Struthers[1*], Gareth P. Harrison[1], Daniel Coles[2], Athanasios Angeloudis[1], R. Camilla Thomson[1]

[1]*School of Engineering, The University of Edinburgh, Edinburgh EH9 3DW, UK*
[2]*School of Engineering, Computing and Mathematics, University of Plymouth, Plymouth PL4 8AA, UK*
**iain.struthers@ed.ac.uk*

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Abstract

Renewable energy from wave energy converters and tidal stream turbines could play an important role in the future power system of Great Britain. However, scenarios of future deployment are highly uncertain and rarely spatially or temporally detailed enough to be used as suitable inputs to power system models. This paper presents a new resource for power system modellers which combines published projections for wave and tidal stream installed capacities with discrete geospatial coordinates of potential deployment sites from the literature to develop 'build scenarios' of future deployment around GB. Three build scenarios (low, intermediate and high) are presented for both wave and tidal stream generation. These scenarios can be used by power system modellers to analyse the contributions of marine energy to the future power system of Great Britain.

1. Introduction

Renewable power generation from wave and tidal stream has the potential to play a greater role in the decarbonisation of the power sector in Great Britain, however, the scale of deployment is highly uncertain [1]. Technical risks for both technologies remain after decades of research and development, while other power generation and flexibility technologies have become more widespread. Nevertheless, the practical resource for both technologies remains significant relative to contemporary demand [2, 3], and recent successes and continued government support could yet encourage future deployment. Wave and tidal stream are particularly advantageous to power system operation due to the temporal difference (complementarity) in the phasing of their power generation relative to other variable renewable generation such as wind and solar [4]. This has the potential to ease network congestion and reduce the requirement for additional flexibility measures, such as backup generation, demand management or energy storage [5].

Potential wave power sites are distributed across the North and West of Scotland and around the South West coasts of Wales and England. Tidal stream sites are highly localised, and are concentrated around the Pentland Firth between mainland of Scotland and the Orkney Isles, as well as the North and West of Scotland, and some Channel Islands [2, 5]. These locations correlate poorly with the existing National Grid transmission system and current centres of load, presenting potential challenges to power system operators. The interaction of the spatial distributions, network capacity and demand centres, have the potential to suppress the utility of wave and tidal stream's differing temporal profiles. Accordingly, it is important that power system models of future energy scenarios capture both the spatial distribution and temporal variability in power generation so that the effectiveness of these technologies can be best understood. No data for such analyses has been identified in the literature, but similar resource datasets are available for solar generation [6].

This paper combines projections from long-term energy system optimisations, tidal stream resource from a multi-scale hydrodynamic model and geospatial coordinates from literature and site development databases to create simple 'build scenarios' for wave and tidal stream around GB in the years 2025, 2030, 2035, 2040, 2045 and 2050. Three projections were selected for both technologies: low, intermediate and high. Chronological construction order is defined by contemporary site development status and available power, and the installed capacity at each site is scaled in every year considered to match long-term projections. Reanalysis data (wave power) and model velocities (tidal stream) are used to produce hourly power generation profiles for use in power system modelling.

2. Methodology

At its core, the methodology presented here is straightforward, comprising the following steps:

1. Identify credible projections for discrete wave and tidal stream deployment around GB for 2025 to 2050.
2. Identify credible wave and tidal stream site locations and the nominal power expected to be installed at each site, as a percentage of the total installed fleet.

3. Determine the chronological order of site development and equate the cumulative site capacity to the installed capacity of future projections.
4. Use publicly available power performance data for a nominal wave energy converter (WEC) [7], in conjunction with open-source reanalysis data for each site [8] to yield a set of capacity factor time series for each site.
5. Develop a nominal power curve for a tidal turbine, combined with predicted tidal stream velocities (from the Thetis coastal ocean model [9]) to yield a capacity factor time series for each site.

2.1. Future projections for installed capacities

Three sources for the future installed capacities were identified representing high, intermediate and low installed capacity scenarios, where the designation refers to the installed capacity in 2050 (Table 1) [10, 11, 12]. These sources are UK-specific, include a detailed breakdown of installed capacity per year and report wave and tidal stream technologies separately. This separation lends internal consistency to the projections for wave and tidal, as opposed to separate references for each technology. A full discussion of the assumptions behind these projections is given in their respective sources [10, 11, 12].

Table 1 Future installed capacities for wave and tidal stream generation [GW].

	Wave (low)	Wave (int.)	Wave (high)	Tidal (low)	Tidal (int.)	Tidal (high)
2025	0	0	0	0.41	0	0.1
2030	0.01	0	0	0.91	0	2.35
2035	0.41	0	4.81	1.41	0.03	4.86
2040	0.91	0.45	6.2	1.91	1.09	15.67
2045	1.41	2.23	11.46	2.41	2.94	15.66
2050	1.91	6.39	21.46	2.91	6.21	15.54

The high projection used the Energy System Catapult's Energy System Modelling Environment (ESME) [10]; a whole-systems model that deploys technologies for all parts of the energy system, to produce a least-cost system capable of fulfilling demand. The primary assumption in this source was that wave and tidal stream achieve a LCOE of £90/MWh by 2030, supported by a Contracts for Difference (CfD) mechanism. The installed capacity of wave and tidal stream in 2050 under this analysis was 21.5 GW and 15.5 GW respectively. This tidal deployment is 35% larger than the 11.5 GW estimated by assessing resource potential, cost, system integration and environmental impacts [2]. The reference identified for the intermediate scenario also used the ESME model, but constrains the build rates to increase cumulatively and assumes that the Strategic Energy Technology (SET) Plan cost targets are met (€150/MWh for wave energy and €100/MWh for tidal stream by 2030) [11]. This results in 6.4 GW of wave power and 6.2 GW tidal stream respectively by 2050. The reference for the low projection is a 2018 report from Offshore Renewable Energy Catapult [12] which assumes an average installation rate of 100 MW per year starting from a nominal demonstration fleet of 10 MW, resulting in 910 MW of wave and 1910 MW of tidal stream by 2040. No data is available post-2040 but continuing this linear deployment rate results in 1.91 GW of wave power and 2.91 GW of tidal stream by 2050.

2.2. Site locations and capacity

The locations and nominal generation capacity of the wave power sites were taken from the UK Marine Energy Database (UKMED) maintained by Renewable UK [13], previously consented sites and recent papers [5]. Duplicate or near-identical sites were amalgamated. The tidal sites were similarly derived [2, 13, 14]. Fig 1 shows the distribution of site relative contribution to the total installed capacity.

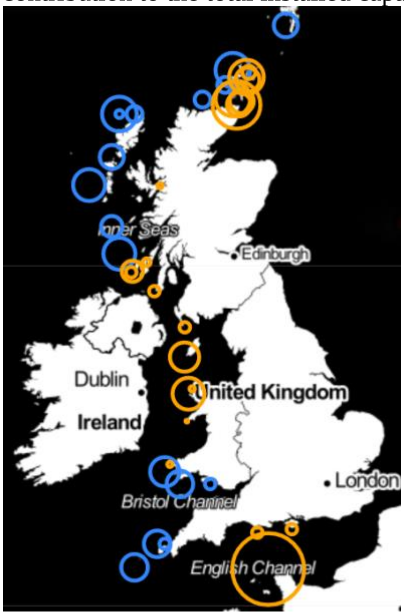

Fig. 1 Location of wave (blue) and tidal (yellow) arrays. The bubble size represents the capacity of in each projection (high, intermediate or low).

2.3. Device power characteristics

The availability of wave energy extraction depends on both the wave height and the wave period. The power matrix for the Pelamis 750 kW wave energy converter was used [7] showing production at different combinations of significant wave height (H_s) and peak wave period (T_p). The power matrix was transformed from terms of energy period (T_e) to peak period (T_p) using a ratio T_e/T_p = 0.884, calculated from a JONSWAP spectrum with a peak enhancement factor of 2. Table 2 shows the resulting power matrix. For tidal stream a nominal power curve (Fig 2) was constructed to emulate the rated power and performance of the Orbital Marine O2 floating tidal turbine [15] using a power coefficient of 0.41 from a contemporary turbine design [16]. As with the wave power approach, only a single converter type was represented, which is expected to lead to low capacity factors at certain sites, when rated velocities are not exceeded regularly.

2.4. Renewable resource data

Predicting wave climate at these time horizons is infeasible. Accordingly, historical reanalysis data was used as a proxy.

Table 2 Power matrix of the Pelamis WEC in terms of significant wave height (H_s, in m) and peak wave period (T_p, in s)

Hs/Tp	5.66	6.22	6.79	7.35	7.92	8.48	9.05	9.61	10.18	10.75	11.31	11.88	12.44	13.01	13.57	14.14	14.70
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	22	29	34	37	38	38	37	35	32	29	26	23	21	0	0	0
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	21	42	37	33
2	57	88	115	136	148	153	152	147	138	127	116	104	93	47	74	66	59
2.5	89	198	180	212	231	238	238	230	216	199	181	163	146	83	116	103	92
3	129	270	260	305	332	340	332	315	292	266	240	219	210	130	167	149	132
3.5	0	0	354	415	438	440	424	404	377	362	326	292	260	188	215	202	180
4	0	0	462	502	540	546	530	499	475	429	384	366	339	230	267	237	213
4.5	0	0	544	635	642	648	628	590	562	528	473	432	382	301	338	300	266
5	0	0	0	739	726	731	707	687	670	607	557	521	472	356	369	348	328
5.5	0	0	0	750	750	750	750	750	667	667	658	586	530	417	446	395	355
6	0	0	0	0	750	750	750	750	750	750	711	633	619	496	512	470	415
6.5	0	0	0	0	750	750	750	750	750	750	750	743	658	558	579	512	481
7	0	0	0	0	0	750	750	750	750	750	750	750	750	621	613	584	525
7.5	0	0	0	0	0	0	750	750	750	750	750	750	750	676	686	622	593
8	0	0	0	0	0	0	0	750	750	750	750	750	750	750	750	690	625

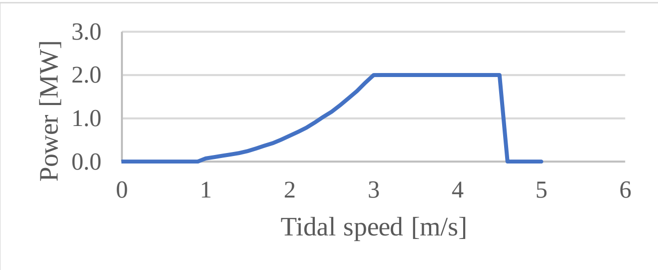

Fig. 2 Nominal power curve assumed for tidal turbine with two rotors. The cut in, rated speed and cut out speeds are 1 m/s, 2.5 m/s and 4.5 m/s respectively. Each rotor is 20 m diameter rated power of 1 MW, power coefficient of 0.41 [15, 16].

The ERA5 dataset [8] was identified as an accessible, publicly available metocean database where the device power matrix parameters of significant wave height (H_s) and peak period (T_p) were readily available. ESOX Map [17], was used to quickly download the reanalysis data. For tidal stream, the Thetis coastal ocean model is applied to simulate the tidal hydrodynamics at prospective tidal sites. The flow velocity components sequentially undergo a harmonic analysis process that extracts the local harmonic tidal constituents. In turn, these are used to reconstruct the depth averaged tidal stream velocities over time and the signal is sub-sampled at hourly resolution at each location [9]. In this way, the tidal stream resource data can be said to be predictive, which contrasts with the retrospective wave resource. The capacity factor was then determined using the nominal tidal turbine power curve, based on ambient flow conditions.

2.5. Cumulative capacity

Determining the chronological order of site development is uncertain, so a two tiered approach was used. The first tier was an assessment of each site's access to revenue support in Auction Round 4 (AR4) of the CfD subsidy scheme. To access support, sites must have a Crown Estate/Crowns Estate Scotland lease plot, be consented, and have grid connection. Currently, MeyGen, Morlais and the Isle of Wight are the only three tidal stream sites that have all three [2], and there are currently no eligible wave power projects. The second tier was the available power at each site, which we use as a proxy for LCOE. For wave power sites, this was estimated based on the annual average of the peak power per wave crest in each hour. For tidal stream sites this was estimated based on the annual average of flow speeds cubed. After ranking the sites in this way for this early stage study, the cumulative capacity of the sites as a percentage was set equal to installed capacity of the projection for that year. Matching the installed capacity and the projections exactly was achieved by installing only a proportion of large sites. However, scaling the nominal installed capacity of each site to match ambitious high future projections could exceed the physical potential resource at some real world sites (e.g.MeyGen). Nevertheless, this is insightful in indicating the excess capacity needed at additional sites not included in Table 3 for the national future projections to be achieved.

3. Results

The outcome of this work is a set of high, intermediate and low build scenarios for tidal stream and wave power deployment around GB, for use with power system analyses (Table 3). While it is not possible to lay out the capacity factor time series data within the constraints of this conference paper, it is possible to provide a short sample time series (Fig 3).

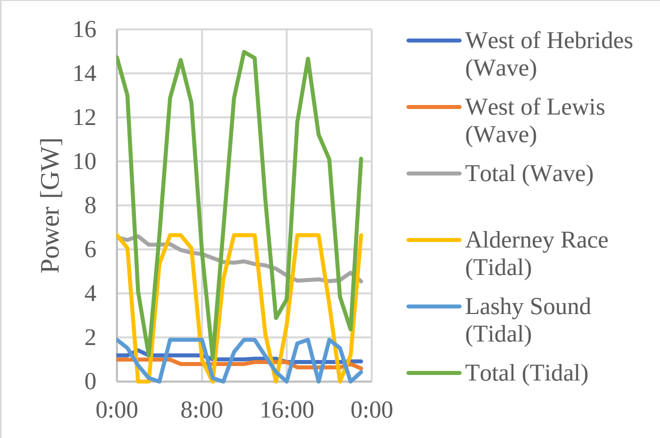

Fig. 3 Historic wave power (2012) and predicted tidal stream (2050) generation from all sites combined, and the top two sites at the spring equinox (21st March) in the high projection.

4. Conclusion

This paper has introduced three build scenarios of wave power and tidal stream generation around Great Britain, for use with power system modelling. These scenarios are consistent with three projections of installed capacity for the years 2025, 2030, 2035, 2040, 2045 and 2050 from the literature and use a simple approach to represent the chronological order of development. In addition, publicly available ocean wave reanalysis data, and predictive hydrodynamic modelling results have been used with nominal device power generation characteristics to develop time series of capacity factor for each site. Combining these data enables the detailed spatial and temporal integration of wave and tidal stream into future energy scenarios.

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Table 3 Installed capacity at each site every five years in the low/intermediate/high projections [GW]. 2025 is omitted from the table as none of the projections considered have reportable wave capacity in 2025, and only MeyGen and Morlais appear for tidal stream with 0.36/0/0.1 and 0.05/0/0 GW, respectively.

Site	Lat	Lon	Capacity	2030	2035	2040	2045	2050
W. of Hebrides	57.25	-8	9.5%	0/0/0	0.2/0/2	0.2/0.5/2	0.2/0.6/2	0.2/0.6/2
Bernera	58.5	-7	0.5%	0/0/0	0/0/0.1	0/0/0.1	0/0/0.1	0/0/0.1
West of Lewis	58.5	-7	9.5%	0/0/0	0.2/0/2	0.2/0/2	0.2/0.6/2	0.2/0.6/2
Tiree	56.5	-7.25	4.8%	0/0/0	0/0/0.6	0.1/0/1	0.1/0.3/1	0.1/0.3/1
Farr Point	58.75	-4.25	2.4%	0/0/0	0/0/0	0/0/0.5	0/0.2/0.5	0/0.2/0.5
Blackstones	56	-7	9.5%	0/0/0	0/0/0	0.2/0/0.5	0.2/0.5/2	0.2/0.6/2
St Mary's Point	49.75	-6.5	9.5%	0/0/0	0/0/0	0.2/0/0	0.2/0/2	0.2/0.6/2
Brough Head	59.25	-3.25	9.5%	0/0/0	0/0/0	0/0/0	0.2/0/1.6	0.2/0.6/2
West Orkney	59	-3.5	2.4%	0/0/0	0/0/0	0/0/0	0/0/0	0/0.2/0.5
Arnol	58.5	-6.5	1.9%	0/0/0	0/0/0	0/0/0	0/0/0	0/0.1/0.4
Penzance	50.25	-5.75	9.5%	0/0/0	0/0/0	0/0/0	0.2/0/0	0.2/0.6/2
Maywick	60	-1.5	4.8%	0/0/0	0/0/0	0/0/0	0.1/0/0	0.1/0.3/1
Harris	57.75	-7.25	4.8%	0/0/0	0/0/0	0/0/0	0/0/0	0.1/0.3/1
Wave Hub	50.25	-5.5	1.7%	0/0/0	0/0/0	0/0/0	0/0/0	0/0.1/0.4
Pem. Demo.	51.5	-5	8.6%	0/0/0	0/0/0	0/0/0	0/0/0	0.2/0.6/1.8
Pembrokeshire	51.75	-5.5	9.5%	0/0/0	0/0/0	0/0/0	0/0/0	0.2/0.6/2
Scarweather	51.5	-4	1.4%	0/0/0	0/0/0	0/0/0	0/0/0	0/0.1/0.3
Wave power total installed capacity [GW]				0/0/0	0.4/0/4.8	0.9/0.5/6.2	1.4/2.2/11.5	1.9/6.4/21.5
MeyGen	58.66	-3.13	12%	0.4/0/1.9	0.4/0/1.9	0.4/0.8/1.9	0.4/0.8/1.9	0.4/0.8/1.9
Morlais	53.32	-4.72	7%	0.2/0/0.4	0.2/0/1.1	0.2/0.3/1.1	0.2/0.5/1.1	0.2/0.5/1.1
Isle of Wight	50.56	-1.3	1%	0/0/0	0/0/0.1	0/0/0.1	0/0.1/0.1	0/0.1/0.1
Kyle Rhea	57.24	-5.66	0%	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
Westray South	59.13	-2.8	6%	0.2/0/0	0.2/0/1	0.2/0/1	0.2/0.4/1	0.2/0.4/1
Lashy Sound	59.21	-2.72	1%	0/0/0	0/0/0.1	0/0/0.1	0/0.1/0.1	0/0.1/0.1
Sound of Islay	55.84	-6.1	0%	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
Alderney Race	49.71	-2.08	43%	0.1/0/0	0.6/0/0.5	1.1/0/6.7	1.2/1.2/6.7	1.2/2.7/6.7
Brims	58.76	-3.25	6%	0/0/0	0/0/0	0/0/1	0.2/0/1	0.2/0.4/1
Islay Demo	55.67	-6.57	3%	0/0/0	0/0/0	0/0/0.5	0.1/0/0.5	0.1/0.2/0.5
Brough Ness	58.72	-2.95	3%	0/0/0	0/0/0	0/0/0.5	0.1/0/0.5	0.1/0.2/0.5
Mull of Galloway	54.62	-4.84	1%	0/0/0	0/0/0	0/0/0.1	0/0/0.1	0/0.1/0.1
Stronsay Sound	59.09	-2.76	3%	0/0/0	0/0/0	0/0/0.5	0/0/0.5	0.1/0.2/0.5
West Islay	55.66	-6.61	1%	0/0/0	0/0/0	0/0/0.1	0/0/0.1	0/0.1/0.1
Portland Bill	50.49	-2.44	1%	0/0/0	0/0/0	0/0/0.1	0/0/0.1	0/0.1/0.1
Ness of Duncansby	58.66	-3.05	3%	0/0/0	0/0/0	0/0/0.5	0/0/0.5	0.1/0.2/0.5
Bardsey	52.78	-4.77	0%	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
St David’s Head	51.9	-5.33	0%	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
Anglesey Skerries	53.42	-4.6	0%	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
Mull of Kintyre	55.3	-5.84	1%	0/0/0	0/0/0	0/0/0.1	0/0/0.1	0/0.1/0.1
Isle of Man	54.04	-4.85	6%	0/0/0	0/0/0	0/0/1	0/0/1	0.2/0.4/1
Tidal stream total installed capacity [GW]				0.9/0/2.4	1.4/0/4.9	1.9/1.1/15.6	2.4/2.9/15.6	2.9/6.2/15.5