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Comparing trade-offs between tidal energy and offshore wind in the United Kingdom

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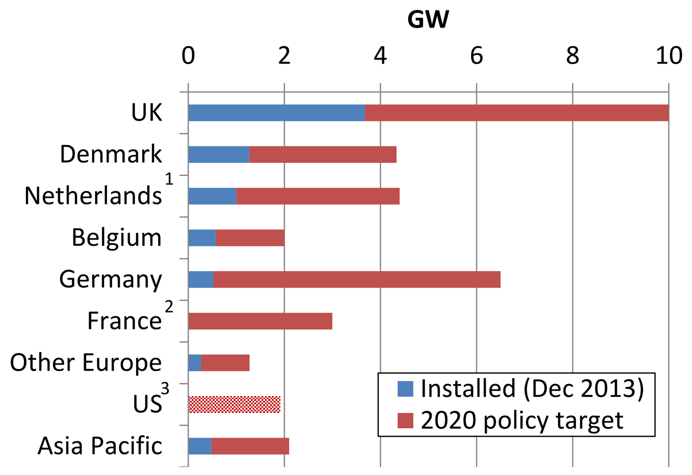
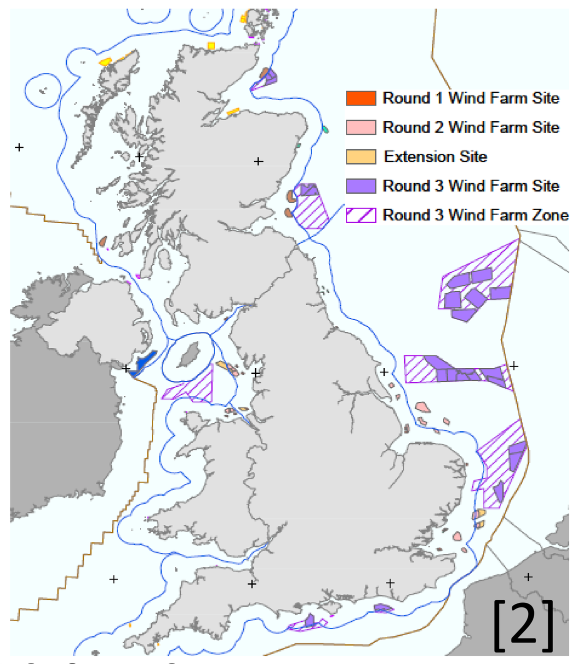
UK market for offshore wind and tidal/wave

Offshore wind currently dominates the marine renewables market with about 8GW installed worldwide (right figure). The UK is one of the leading markets, with almost 4GW currently and 10GW projected by 2020.



Based on market analysis and stated 2020 policy goals

1. 2023 policy target
2. 50% of the stated 2020 policy target
3. No existing goal in place. Assumes 50% attrition of existing projects as reported by DOE [1]

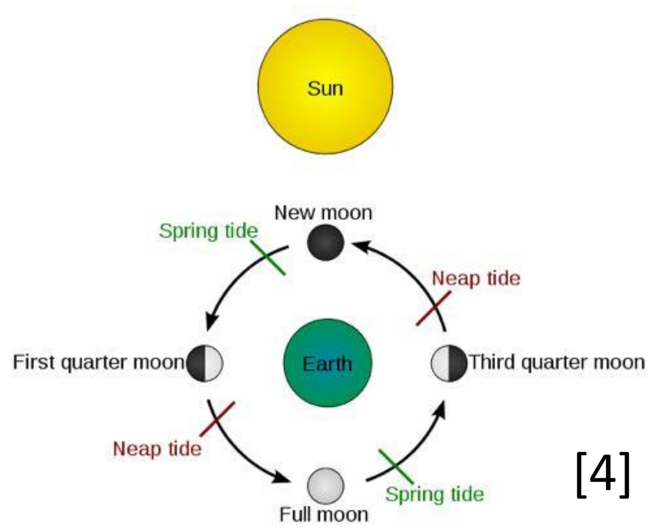


The UK government offers up to £155/MWh for 15 years to support offshore wind projects. The Crown Estate has begun offering round 3 leases (left figure) for large-scale projects, beyond 1,000 MW.

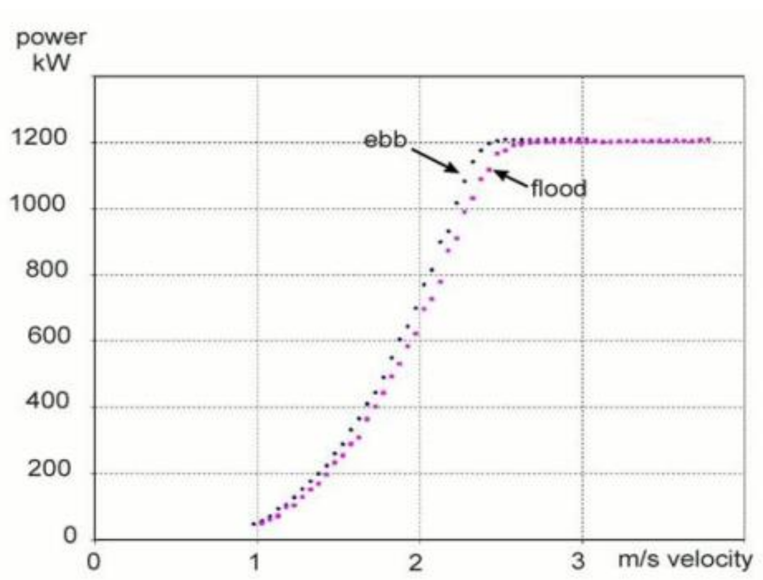
Tidal and wave energy are of growing interest in the UK with up to 50 GW of projected technical potential. As of 2013, 12 prototypes have been installed in the UK, although total capacity is less than 10 MW. The UK government currently offers feed-in-tariffs of £ 305/MWh for 15 years to support up to 50 MW total for new tidal/wave projects. [3]

How do tidal energy converters (TCE) produce energy?

Tides change as a result of the gravitational force of the moon. This causes daily tidal changes (2 high and low per day), monthly conditions (spring and neap, 2/28-day period), and seasonal patterns. "Tidal currents" are created when tides change and are strongest between high and low tide (ebb tide). In the UK, this results in 4 peaks per day.

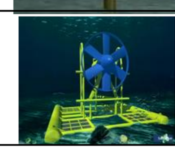
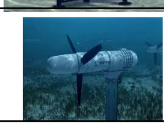


This research focuses on tidal energy converters (TCE), which use submerged turbines with rotor diameters of 10 to 25 m to generate up to 2,000 kW of power from tidal currents (>1 m/s). The left figure shows the power curve from a prototype TCE with two 16m diameter rotors located in Northern Ireland. Its rated capacity is 1.2MW and has an annual capacity factor of over 65%. [5]



SeaGen at Strangford Narrows: Power Curve

Leading tidal stream technologies

Company	Photo	Size*	Commercial Projects
OpenHydro (France, 2005)		2 MW (16 m)	2011: 2 MW @ Paimpol, FR 2015: 4 MW @ Bay of Fundy, CA 2016: 14 MW @ Raz Blanchard, FR *Prototypes: 2 since 2006*
Andritz Hydro Hammerfest (Norway, 1997)		1 MW (20 m)	2011 : 1 MW @ EMEC, Scotland 2015+ : 10 MW @ Sounds of Islay, UK *Prototypes:* *2003: 300 kW @ Kvalsund, NOR, first grid connected*
**Marine Current Turbines/Siemens (Germany, 1999)		2 MW (20 m)	2016+: 6 MW @ Allegheny, Skerries, UK *Prototypes:* *2003: 300 kW prototype @ Devon, UK* *2008: 1 MW prototype @ Northern Ireland*
Sabella (France, 1999)		0.5 MW (10 m)	*Prototypes:* *0.5 MW @ Fromveur Passage, FR (2014)* *300 kw @ Benodet, FR (2008), first in FR*
Atlantis Resources (Australia, 2002)		1 MW (18 m)	2010: 1 MW @ EMEC, UK 2011: 1 MW @ Bay of Fundy, CA 2012: 1 MW @ NaREC (Blyth), UK 2015: 6 MW @ Pentland Firth, UK *Prototypes: 3 since 2006*
ALSTOM (France, 2005)		1 MW (16 m)	2013: 1 MW @ EMEC, UK 2016+: >1 MW @ Raz Blanchard, FR *Prototypes: 1 since 2010*
Voith Hydro (Germany, 2006)		1 MW (13 m)	2013: 1 MW @ EMEC, UK 2016+: 3 MW @ Raz Blanchard, FR *Prototypes: 1 since 2011*

Information above is from company websites and news articles

* Capacity and rotor diameter (m) of tidal energy converter (latest design). All turbines reach rated capacity between 2 to 3 m/s tidal current speed.

** All turbines are fully submerged and directly fixed to the seabed except Marine Current Turbines, which instead uses a monopile and horizontal crossbeam -- to which 2 turbines are attached -- to raise turbines above the surface for O&M.

Potential Advantages of TCEs over offshore wind

- **Predictability of power**: Tidal flows are highly predictable and thus tidal energy offers more reliable power to the electricity grid than wind farms.
- **Variability is still a problem** with TCEs since the power source is not controllable. However, some technology providers claim that their device can provide firm power over specified intervals due to high predictability.
- **Limited visual impact**: TCEs are designed for depths of 35 to 100 meters and thus present limited visual impact. Some turbines (Marine Current Turbines) have a surface-piercing component. However, even this structure is only 25 meters above water compared to an offshore farm, which is over 120 meters above water.
- **Different ecological impacts:** The main concern with TCEs is impact to marine mammals. Offshore wind farms face consenting challenges with bird and bat migration.

Proposed method to evaluate TCE benefits

Cost premium for TCEs over offshore wind farms: By comparing two similarly sized projects-- an operational offshore wind farm off the coast of Northeast England and a hypothetical TCE in the same area– this research proposes to calculate the additional benefits ("cost premium") that the TCE could offer over the offshore farm.

Cost premium = (1) + (2) + (3)

(1) value of predictable tidal power = cost of unpredictable power from offshore wind

$$\text{(1)} \quad \text{Variability Cost}(h) = \sum_{k=1:n} |\varepsilon_k| P_h / n + P_{up,h} \left| \min\begin{Bmatrix} 0 \\ \min(\varepsilon) \end{Bmatrix} \right| + P_{dn,h} \left| \max\begin{Bmatrix} 0 \\ \max(\varepsilon) \end{Bmatrix} \right|$$

$$\text{(2)} \quad \text{Normalized Cost} = \frac{\sum_{h=1:8760} \text{Variability Cost}(h)}{\sum_{h=1:8760} \sum_{k=1:n} S_{k,h} / n}$$

Equations and method borrowed from [6]

Where:

P_h	is the hourly price of energy	(a)
$P_{up,h}$	is the hourly price of up regulation	
$P_{dn,h}$	is the hourly price of down regulation	
q_h	is the amount of firm hourly energy forecasted	(b)
$S_{k,h}$	is the actual subhourly production of energy in hour h	
$\varepsilon_k = S_k - q_h$	is the difference between energy forecasted and produced	
n	is the number of energy production records per hour (60 for TEP, 12 for NSO, 4 for ERCOT wind, and 60 for the 20 MW+ PV array)	

(a) Ancillary service and energy prices from UK electricity market

(b) Hourly forecast and historical offshore wind generation provided by EDF ER

(c) TCE power production based on publically available tidal current data and an assumed power curve from one of the leading tidal technologies (**still in progress**)

(2) value of reduced visual impact = reduction in housing prices due to onshore wind development based on results from econometric models developed in [7] and [8]

(3) value of power produced =

$$\sum_{hour} (\underset{(a)}{\text{UK electricity spot prices}_{hour}}) * (\underset{(c)}{\text{TCE energy}_{hour}} - \underset{(b)}{\text{offshore farm energy}_{hour}})$$

Expected/ Preliminary Results

By calculating the "cost premium" for TCEs, this research would give policymakers and investors a sense for how large the gap can be between the costs for offshore wind and tidal energy before tidal projects become too costly. Currently, the cost gap is about £100-150/MWh.

Preliminary "back of the envelope" results show that the **cost premium for tidal energy ranges from £5 to £50/MWh**. This suggests that the **cost of TCEs must decrease by at least 35%** for tidal energy to be more socially optimal than offshore wind.

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[8] Stephen Gibbons, "Gone with the wind: valuing the local impacts of wind turbines through house prices," Preliminary Draft, November 2013.