Variability of wave and tidal stream energy

Development of wave and tidal stream energy generation technology offers a real opportunity to diversify the UK's electricity generation capacity. But to incorporate these renewable energy sources within the UK electricity system, it is necessary to recognise and quantify their likely patterns of generation, in particular the nature and extent of variability over time. Such variability occurs as natural characteristics of the resource, for example the cycle of tidal flows in and out of estuaries.

It is necessary to examine resource variability on an electricity system-wide basis in order to understand technical implications for security of supply, grid capacity, power quality and network design and management. It is also important to understand economic aspects of variable renewables supplying the electricity system, including the capacity of despatch-able generation that is required to 'back-up' variable renewables and the costs of balancing supply and demand with variable renewables forming parts of supply mix.

Such issues are frequently raised about wind power and have been addressed for this technology in previous studies, (see for instance the Carbon Trust/DTI Renewables Network Impact study). New investigations for wave and tidal stream energy were made during 2004-05 as part of the Marine Energy Challenge (MEC).

This article summarises the MEC work on variability and links to two reports commissioned from the Environmental Change Institute at Oxford University. These reports are as follows:

- Variability of UK marine energy resources. This describes the variability characteristics of UK wave and tidal stream energy resources and discusses implications for large scale development.
- Diversified Renewable Energy Resources. Based on scenarios for the future UK supply mix, including wave and tidal stream energy, this considers economic and grid-integration aspects of variability.
- Readers may also be interested in work published by:
- The Scottish Executive, which gives results and draws conclusions in context of the Executive's target of meeting 40% of Scotland's demand for electricity by renewables in 2020. This work was conducted by the University of Edinburgh, and is available here.
- The UK Energy Research Centre (part-funded by the Carbon Trust), which takes a more general look at variability and intermittency, makes policy recommendations and identifies issues for further research.

What are the key variability characteristics of UK wave and tidal stream energy resources?

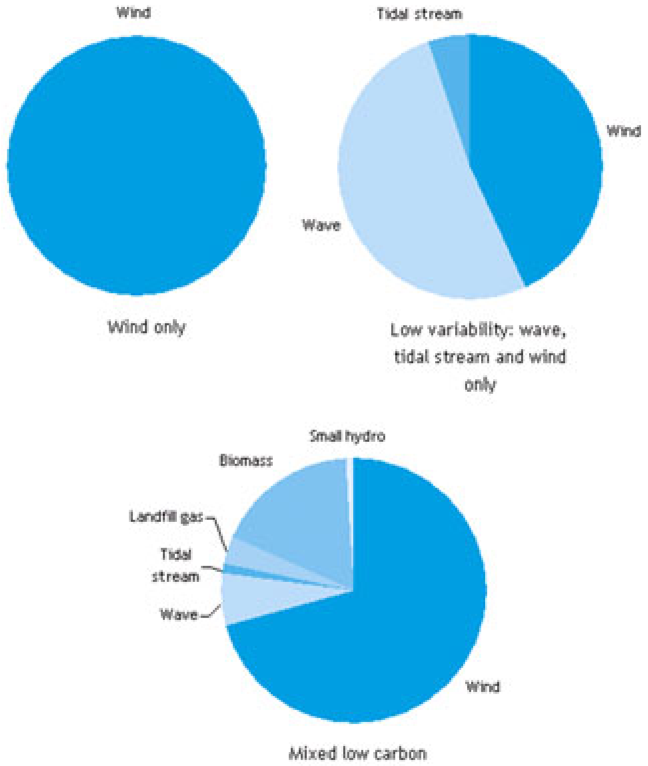
- The UK's wave resource is region-specific, with the southwest and north coasts having the greatest wave energy. Within any region, the wave climates at individual sites are broadly similar, but are affected by local conditions including water depth and bathymetry (seabed shape). Average UK wave power levels exhibit clear seasonal trends; waves are more energetic in the winter than the summer. Almost half of the wave power available annually around the UK occurs during December, January and February.
- The UK tidal stream resource is site-specific and dominated by two superimposed cycles. The semi-diurnal cycle (two high tides and two low tides per day) is unique to particular sites, and sites may be out of phase with each other. The spring/neap cycle on the other hand, (which repeats every 14 days, and has the effect of increasing peak velocities in both ebb or flow), occurs at all sites simultaneously. There are no significant seasonal trends.

How does UK wave and tidal stream resource variability compare to demand variability?

- There is a strong correlation between times of high wave energy and high electricity demand. Wave power has the potential to deliver over 3 times more power during peak demand hours than at times of low demand (dependent on wave site). Actual power output does vary during the high demand hours, but the chance of low wave power output is much less than during low demand periods.
- Tidal stream generation patterns differ significantly to electricity demand cycles. Maximum power output sometimes coincides with peak demand, but at other times minimum power output does. However, at likely penetration levels, the magnitude of tidal stream supply variations is small compared to demand variability.

If power from UK wave, tidal stream and other variable renewables was combined, how would diversity of both generation technologies and geographic locations affect overall supply variability?

- The total power generated at several, geographically diversified high wave energy sites exhibits lower variability than at any single site. Tidal stream generation variability can also be reduced by combining sites at different locations, but the degree to which this can be achieved is highly dependent on the individual tidal power sites that are developed.
- Overall variability [1] can also be reduced by combining wave, tidal stream, wind and other plants together in certain weightings. The study identified a combination of wave, tidal stream and wind power that has a lower overall variability (2.0%) than wind power alone (3.2%). This is 8.6% wind, 10.4% wave and 1.0% tidal stream, together contributing 20% of total UK supply, with the other 80% coming from conventional capacity. Of course, the actual penetration of renewables depends on a range of factors and other forms of low carbon generation should also be taken into account. For comparison, an alternative, mixed low carbon scenario including wind, wave, tidal stream, landfill gas, biomass and small hydro power was also considered. Notably, this contains much smaller proportions of wave and tidal stream power [2]. The overall variability was estimated to be 3.0%.
- A further potential benefit of combining different variable renewables is increased grid capacity utilisation, but this was not quantified during the study.



Generation mix scenarios referred to in the variability study. Each pie represents 20% of total UK generation, with the other 80% coming from CCGT.

If wave energy converters and tidal stream energy generators were installed as part of a mixed generation portfolio, which also included conventional (despatch-able, thermal) generation, what would be the likely capacity credit [3] and extra balancing costs [4,5]?

- The capacity credit of wave, tidal stream and wind energy depends on several factors but is strongly influenced by the overall variability and amounts of capacity installed. The table below shows the conventional capacity required for a conventional electricity system, and for the three different low carbon generation scenarios already mentioned, (wind only, a low variability combination of wave, tidal steam and wind, and a mixed low carbon generation portfolio). For the low variability scenario, the capacity credit is around 6 GW, which is higher than the wind only scenario. The additional balancing costs are around £1.80/MWh, which is less than the wind only scenario because the overall variability is lower.
- Again, since the penetration of wave, tidal stream and wind depends on a range of factors, and other forms of low carbon generation should be recognised, one can compare to the mixed low carbon scenario. In this case, the capacity credit is 6.5 GW and the extra balancing costs are £2.70/MWh. The differences between the two scenarios are mainly due to the smaller contribution of wave power (and higher contribution from wind power).

Scenario	Generation mix	CCGT capacity [GW]	Capacity credit (renewables capacity)	Extra balancing costs [£/MWh]
No low carbon generation	CCGT 100%	84	Not applicable	Nil
Wind only	CCGT 80%, wind 20%	79	5	2.85
Low variability wave, tidal stream and wind	CCGT 80%, wave, tidal stream and wind total 20%	78	6	1.80
Mixed low carbon	CCGT 80%, wave, tidal stream, wind and other low carbon sources total 20%	77.5	6.5	2.70

How well can the output of wave and tidal stream energy be predicted?

- The ability to make accurate predictions of wave, tidal stream and wind power output has an important bearing on grid integration, and good predictions may be used to reduce balancing costs. Wind power predictions have been studied previously. By nature, tidal stream resources are highly predictable at almost any time horizon, although site measurements can improve forecast accuracy and events such as storm surges may have an impact on the timing of generation.
- Wave power can be predicted to different degrees of accuracy and consistency over different time horizons. At energetic sites, wave power exhibits a high degree of persistence, which means that the power output in the next hour is likely to be similar to the last. Predictions of conditions a few hours ahead can be made by referring to the power generated during the last hour and wave forecast models.
- The performance of the UK Met Office 'UK waters' model in the specific application of predicting wave power production was evaluated during the study. Predictions were found to be good for high power, offshore wave conditions, at time horizons of up to several days ahead. This is encouraging for offshore wave energy developments. Forecasts were less accurate during periods of low wave power – this is not considered a significant handicap given the limited output of wave power devices during these periods. Notably, predictions of power output were better than predictions of power input (energy carried by the waves), because conversion to electricity has a smoothing effect.

Footnotes

[1] The standard deviation of differences between hourly output levels, expressed as the percentage of variable installed capacity.
[2] The mixture of low carbon generation sources in the alternative scenario was as follows: wind 14.1%, wave 1.3%, tidal stream 0.2%, landfill gas 0.7%, biomass 3.5%, small hydro 0.2%
[3] Capacity of thermal plant displaced.
[4] Costs of scheduling and utilising additional reserve and frequency response to manage the additional uncertainty due to wave and stream energy, above the normal uncertainty in balancing supply and demand, to maintain current levels of power quality and security of supply
[5] These questions have already been addressed for wind power, as discussed in the Carbon Trust/DTI Network Impacts Study.