The UK Market for Marine Renewables

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INTRODUCTION

Renewable energy is the term used to describe a wide range of naturally occurring, replenishable energy sources. At present 15%-20% of current global energy needs are met from such renewable energy sources (mainly traditional biomass, hydro electricity, wood and geothermal sources). Newer renewable energy technologies have the potential to meet an increasing proportion of global energy needs over the coming decades. These technologies include marine-based renewables: offshore wind, wave and tidal energy. This report will present an estimate of the potential market for marine-based renewables in the UK.

The future prospects for particular renewable technologies will be determined by the commercial availability of that technology, the presence of an exploitable resource, the economic competitiveness of the technology compared to other available options, and the overall demand for energy. Therefore, analyses to explore future prospects are complex and results highly uncertain. Because the technologies are at different stages in their development the resource-cost curves derived in this paper are not strictly comparable. For example the onshore wind energy curves are derived from the costs of actual wind farms currently being constructed, whereas those for tidal energy are based on a combination of theory and design studies and are therefore much more speculative and uncertain.

OFFSHORE WIND

Background to Offshore Wind Development

Wind power has been harnessed by mankind for over 2,000 years through the construction of windmills producing mechanical power. The more modern concept involves the conversion of power contained in masses of moving air into rotating shaft power which can then be converted to electrical power.

Onshore wind energy is one of the more promising renewable energy sources for electricity generation worldwide. The UK Government has encouraged the commercial exploitation of wind energy in England, Wales, Scotland and Northern Ireland through NFFO and its sister schemes, the SRO and the NI-NFFO. This has resulted in the commissioning of 57 projects with a total declared net capacity of 137 MW (by end September 1998). Whilst this is impressive, it should be viewed in terms of the total number of onshore wind energy projects supported by NFFO during this time (273) and their net capacity (1016 MW). One of the reasons for the lack of progress on the majority of projects is the difficulty in obtaining planning permission. In some cases local authorities judge that the mainly local environmental impacts (e.g. change in landscape) outweigh the global benefits of the project, such as the contribution made to the reduction in greenhouse gas emissions. This explains, in part, the recent move towards exploiting the offshore wind energy resource.

In addition, the offshore wind resource is potentially much greater than that onshore. It is limited only by the practicable working water depths, the use of maritime areas for other activities and the characteristics of the onshore electrical network. Moving from onshore to offshore need not require major changes in the technology, but additional technical problems arise because of the more hostile environment.

Over the last few years there have been a number of developments which indicate that the costs of exploiting the vast offshore resource may be more economically attractive than they first appeared. Among these are the more rapid development of bigger and cheaper turbines (bigger turbines are required offshore to offset the larger costs of supporting structure and installation). Additionally, wind plant has developed considerably and its performance has improved over previous assumptions.

Offshore Wind Resource

The UK coastal wind resource is mostly in the band 8-9m/s at the reference height, except in shallow waters close to the coast (7-8m/s). In exploiting this resource, certain constraints have to be observed:

- A maximum water depths of 40 m
- A maximum distance offshore of 30 km
- Slope of sea bed no greater than 5°
- Avoidance of certain regions shown on navigational charts: shipping lanes, military zones, pipelines, cables, etc.

If it is assumed that this resource would be exploited by 1.5MW turbines, spaced five rotor diameters apart (to avoid wake interference), then the maximum total capacity would be about 35 GW, which is a large fraction of the peak UK power demand of 50GW.

However, there are many more possible constraints on implementation, i.e.:

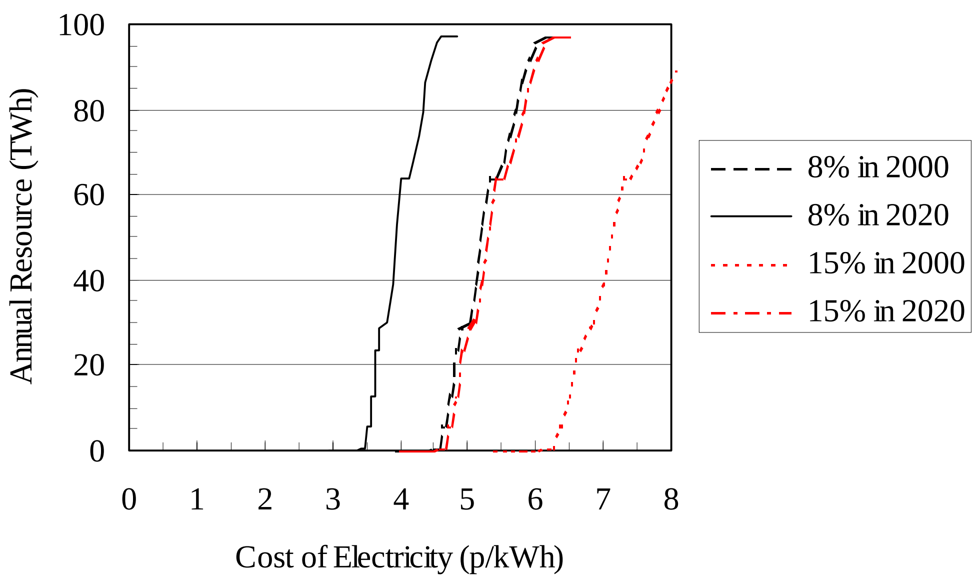
- The presence of unfavourable sea bed conditions
- The availability of grid-connection points
- The effect on the visual amenities of the shore
- Limitations from wildlife conservation areas, (e.g. bird migration routes)
- The exclusion from areas used for military or defence purposes

Therefore, further plausible assumptions based on these constraints were applied to the resource. This reduced the predicted resource to about 100 TWh/year. At 33% of the average UK demand, this is probably slightly over the maximum allowable penetration of an intermittent renewable energy source. It could be reduced further by network constraints, arising either from the nature of the network beyond the shore connection, or from limitations on the total amount of non-firm power that can be managed on the national network as a whole.

Offshore Wind Costs
Current information on costs is limited, but cost data from recent proposals for near-shore wind energy schemes indicates that they might be developed for around £1,000 per installed kW, in shallow water (0-10m) up to 5km from the coast. The construction of large offshore arrays in deeper water and further from the coast is likely to incur greater costs, particularly for sub-sea cabling, support structures and O&M. These costs, their rate of increase and potential future cost reductions have been quantified to make calculations of development costs possible. The resulting resource-cost curve for 2000 and 2020 are shown in Figure 1. These correspond to a market of £ 25-35 billion.

There are several factors which could affect the cost resource curve shown in Figure 1, e.g. uncertainties in the cost of offshore schemes, availability of suitable network connection points and technical challenges posed by the hostile environment. Clearly, before such a large renewable resource can be successfully developed, it is likely that there will need to be initial demonstration wind farms to verify costs, performance and materials durability. These schemes are currently under construction in the UK and small schemes have been built abroad. If these fulfil their potential, offshore wind energy will start to make a significant contribution to meeting electricity demand in the near future.

Figure 1: Resource-Cost Curves for Offshore Wind in the UK



WAVE ENERGY

Background to Wave Energy
Waves form a potentially large world-wide resource estimated at more than 2 TW (WEC, 1993). There are several regions around the world with high incident wave power levels, which are particularly well situated to exploiting this renewable energy source. This includes the UK which has one of the best wave climates in the world.

To date, the attempts to design and deploy cost efficient devices have met with limited success. About 15 prototype devices have been deployed world-wide, mainly in the 1980's, and wave energy is used to power several hundred navigation buoys. However, the last five years have seen a resurgence of interest in wave energy throughout the world, with several companies currently developing and deploying new devices that represent a significant improvement over older concepts. This has been aided by the DTI restarting its programme of support for R&D in wave energy and the inclusion of wave energy for the first time in one of the renewables orders (SRO3). These developments have resulted in the first commercial wave energy device being installed on the shore of Islay last year (see Wavegen at this Conference), with plans for an offshore device in 2002 (OPD, 2001).

Other commercial schemes are soon to be deployed overseas:
- In Australia, an advanced shoreline device is being deployed by Energetech, which already has a power purchase agreement with the local utility. Enquiries for orders have been received from several other countries and several contracts are in the process of being drawn up (Energetech, 2001).
- In Ireland, a 400 kW floating device (the McCabe Wave Pump) has been tested as a pilot scheme and a commercial size device is nearing completion.
- In the Netherlands, another floating wave device (the Archimedes Wave Swing) has been developed by Teamwork Technology. A 2 MW device is nearing the end of construction in Romania for deployment near Portugal (Teamwork, 2001).
- A floating wave energy device developed by Ocean Power Technology in the USA has been tested at a large scale in the Eastern Atlantic and the first commercial schemes are being built in Australia and in the Pacific, with a number of other schemes in the pipeline.

Nevertheless, despite these achievements, wave energy is clearly less mature than offshore wind.

Wave Energy Resource
Wave energy can be considered as a concentrated form of solar energy. Winds are generated by the differential heating of the Earth. As they pass over open bodies of water they transfer some of their energy to form waves. Therefore, the accessible resource depends on the:
- length of coastline or offshore regions exposed to waves
- size of the area over which winds blow to generate waves (the fetch)
- strength of the winds generating the waves.

The resource was estimated by studying the wave climates at key areas around the UK. This utilised the Meteorological Office's wave prediction model at 15 locations around the western coastline of the British Isles to calculate the deep water wave climate for the period from February 1983 to July 1986. The nearshore and shoreline wave energy resources were calculated using a combination of spectral analysis techniques and a computerised refraction and energy dissipation model. The accessible resource in deep water was estimated to be 600-700 TWh/year and that for the nearshore at 100-140 TWh/year.

Numerous ‘hot spots’ were identified along the coastline, where wave energy was concentrated. For 78 of these sites, a more detailed analysis was carried out by running the ray model in reverse and by taking into account the effect of energy dissipation from sea bed friction. The shoreline resource is based on only these most suitable sites was predicted to be 2 TWh/year.

There is potential for the development of both large- and small-scale wave energy systems in the UK. The major factors that determine the size of the practicable resource that such schemes could provide are:

- the distribution and magnitude of wave power levels
- technical limitations (e.g. the efficiency with which wave energy can be captured and turned into electricity, availability of the scheme, etc)
- economic considerations (i.e. ignore areas with low wave power levels)
- environmental considerations (e.g. acceptable numbers of nearshore and shoreline devices, avoiding ecologically sensitive areas, etc)
- other (e.g. provision of shipping lanes, avoiding Ministry of Defence test areas, etc).

Taking into account these considerations, the accessible resource would be reduced to the practicable resource shown in Table 1.

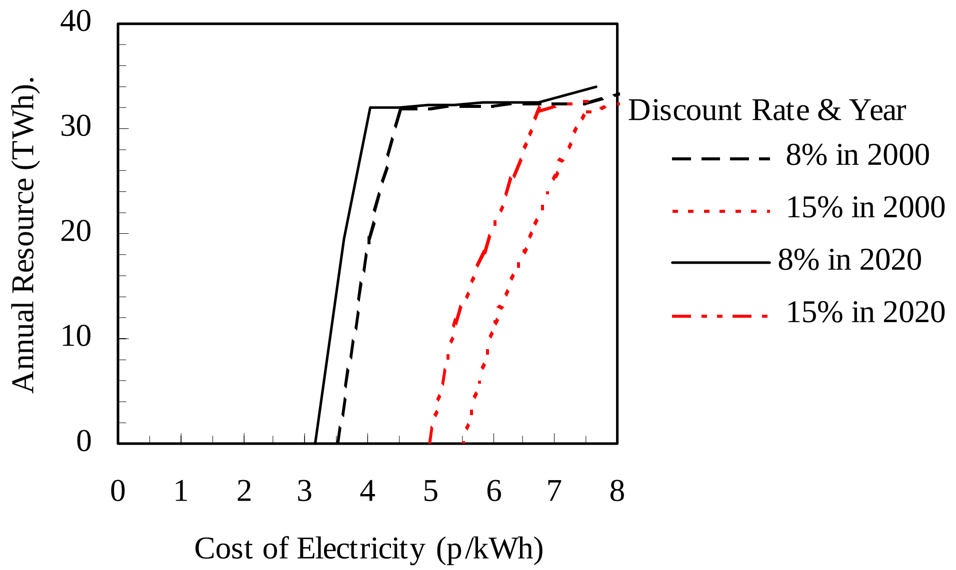
Wave Energy Costs

The few commercial schemes constructed or under construction mean that the cost and performance of wave power generation has to be estimated using a costing model applied to representative devices. This model covers capital costs (including connection to the nearest suitable part of the HV transmission grid) and annual costs (including operation and maintenance). The resulting cost resource curves are shown in Figure 2 and these correspond to a UK market of up to £ 15-20 billion.

Table 1 UK Wave Energy Practicable Resource

Location	**Annual Energy Production (TWh)**
Shoreline	0.4
Nearshore	2.1
Offshore	50.

Figure 2 Resource-Cost Curves for Wave Energy in the UK



The assumptions used in deriving these results, involve some degree of uncertainty but are considered justified in evaluating the cost of a technology at a relatively early stage of development. This was the same approach as used in the UK Wave Reviews (Thorpe, 1992 and 1998) and has the benefit of being extensively peer-reviewed. It is generally accepted as producing good estimates of the likely electricity costs, assuming successful completion of all outstanding R&D.

After economics, the main constraints on the deployment of wave energy technology is the demonstration of cost-efficient energy production for a sufficient length of time to overcome the credibility problems left after the "failure" of early devices and programmes. Given that a number of commercial demonstration schemes are now under construction, large-scale deployment of wave energy devices is expected to start in the next 2-5 years, although some companies have a shorter timescale than this.

TIDAL STREAM ENERGY

Background to Tidal Stream Energy

Useful energy has been obtained from the flow of water currents for centuries. This has been in the form of waterwheels in rivers and estuaries or (more recently) tidal barrage schemes, which use the rise and fall of tides to store water behind a barrage, thereby storing potential energy. Tidal stream technology produces electricity from the kinetic energy in the tidal currents that are produced by the rise and fall of the tides. These currents usually have a low velocity but this can be modified by the local topography. In particular, the velocity can be greatly magnified in straits between islands or between islands and the mainland. The tides can be predicted with high accuracy; hence, after measurements at a site, the energy available for conversion can be forecast with confidence.

The technology is conceptually simple: a suitable tidal flow turns a rotor submerged in the sea, which powers a gearbox and generator. This technology can avoid the need for the massive and expensive civil engineering works associated with tidal barrages. In many ways it is analogous to (submerged) wind turbines, except that

- The greater specific gravity of sea water results in much higher energy densities in tidal streams than found in winds of the same velocity.
- Water velocities available in tidal streams (typically rated velocities of 2-3m/s on good sites) are much less than the air velocities used by wind turbines.

Power output is proportional to the density of the medium and the cube of its velocity, so tidal stream rotors in good sites would produce greater output than wind turbines of the same size.

Small-scale (< 100 W) tidal stream turbines have been produced commercially for some time for use in rivers and estuaries. Larger tidal stream devices (> 1 kW) are in the R&D phase and include:

- A 10 kW floating, horizontal axis turbine (Paish and Fraenkel, 1995).
- A three bladed vertical axis turbine rated at a few kW (Kihoh *et al*, 1985 and 1993).
- A 130 kW, prototype, vertical axis turbine currently being deployed in Strait of Messina (Enermar,2000).

IT Power in the UK plans to follow up its successful testing of its 10 kW floating, device with a 300 kW, bottom standing, horizontal axis device and has plans to increase this to at least 1,500 kW in later schemes. The prototype scheme is scheduled for deployment in the south-west of England.

Teamwork Technology in the Netherlands has developed a design for a modular marine and river current rated at about 25 kW: the “Tocardo”. Tests have been performed on prototype and a demonstration system comprising 25 kW turbines is planned for 2001.

Tidal Stream Resource

The UK has some of the best sites for the exploitation of tidal currents. The major factors that determine the size of the resource are the velocity of the tidal current and the volume through which it flows. Tidal stream data are provided in Admiralty Tidal Stream Atlases. A survey of these identified the promising areas for tidal stream exploitation as:

- Pentland Firth, Northeast Scotland;
- Rathlin Island, Northern Ireland;
- Mull of Galloway, Southwest Scotland;
- Barry Island, Bristol Channel;
- Portland Bill, Southern England;

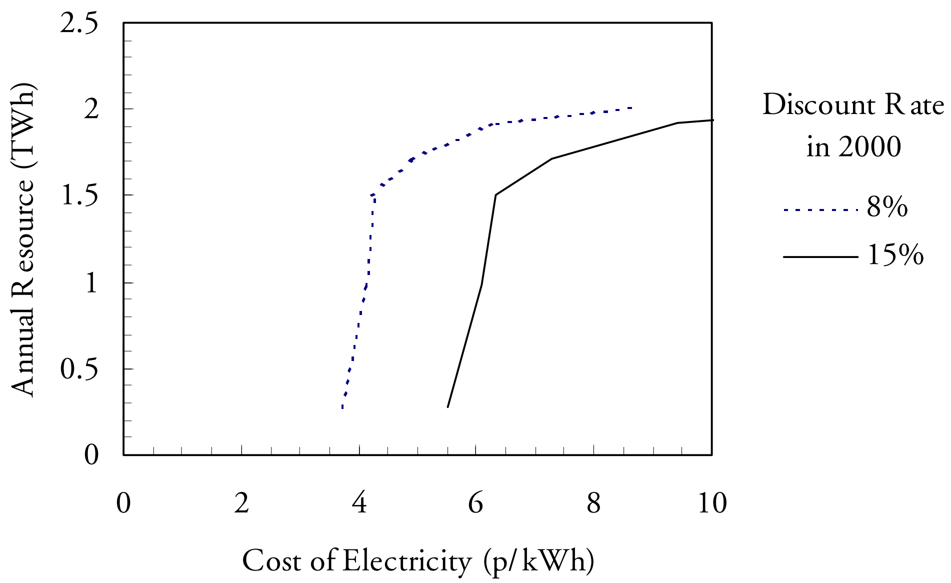
These locations had maximum tidal stream velocities ranging from ~6 ms^{-1} in the Pentland Firth to ~2.5 ms^{-1} in the Mull of Galloway and Rathlin Island. The tidal stream velocities in the rest of the UK were much small than this.

The annual electrical output was evaluated for each area assuming 15 m diameter turbines with a 35% efficiency deployed at 30 m spacing. The accessible tidal stream resource for the most suitable sites in the UK (including the Channel Islands) is estimated to be approximately 36 TWh/year. The actual resource is higher but the current velocities in the remaining areas are so low that their exploitation would be hopelessly uneconomic. However, the nature of the sea bed was not taken into account (e.g. rocky sea beds could preclude the more cost-effective monopile construction).

Tidal Stream Costs

The lack of commercial schemes means that the cost and performance of tidal stream generation has to be estimated from a model similar to that used above for wave energy. The resource-cost curves were derived using data for the best sites around the UK. This assums a mature and successful technology similar to that being developed by IT Power (i.e. a piled support structure supporting two horizontal axis turbines mounted on a cross spar), which is the nearest to commercial success. The resource is derived assuming a single line of turbines and the results are shown in Figure 3, indicating an economic resource of up to 2 TWh/year corresponding to a market of £ 1-1.5 billion. This resource and market could be increased by installing arrays of devices at each site but the efficiency of an array would be less than a single file of turbines, at least until channel blocking starts to take effect. No predictions were made for future costs of this technology, because the lack of any data on schemes of this type installed in the sea would make such predictions spurious.

Figure 2   Resource-Cost Curves for Tidal Stream Energy in the UK



CONSTRAINTS

These marine renewables face a set of common constraints.

- **Institutional**. The environmental disruption caused by wave energy devices in the shoreline/nearshore areas will necessitate an extensive and expensive consultation process, because of the number of statutory bodies that have an involvement in our coastline and surrounding waters.
- **Conversion and Transmission of Energy.** The installation of structures in the sea and cable laying will result in a loss of species on the sea bed. However, there are no rare or endangered species in the most suitable areas and the ecology of these species is likely to recover after installation. The associated onshore works and transmission lines will have a visual impact, which would be unacceptable at some sites. For instance, the northern side of the Pentland Firth is designated a National Scenic Area, whilst the nearest mainland to Rathlin Island is designated as an Area of Outstanding Natural Beauty, with the Giant's Causeway (a World Heritage Site) being 10km to the west of Rathlin Island.
- **Installation**: this will cause a disturbance to local mammals (e.g. seals and dolphins). Providing the timing of the installation is chosen carefully, there should be little effect and these species are likely to return to the areas after installation. During operation, tidal stream turbines could cause mortalities amongst the local fish and mammal populations. The magnitude of this effect is not known but, in view of the slow speed of rotation of the blades, it is expected to be small.
- **Landworks**. These could have an effect on local ecosystems, so careful site selection is needed. Some of the most promising sites for tidal stream energy have special importance in this respect (e.g. Portland Bill has Sites of Special Scientific Interest and a RAMSAR site).
- **Transmission.** There are limited locations around the coast where there are suitable points on the grid for connecting large-scale schemes. In addition,

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