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MARINE ENERGY

This paper examines existing literature on marine energy, focusing on potential resource, economics, variability, grid capacity and job creation

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EXECUTIVE SUMMARY

This paper provides an overview of existing research into wave and tidal energy examining issues such as resource availability, economics, variability, grid capacity and potential job creation.

Wave Energy

The global economically exploitable wave energy resource is estimated to be in the region of 140-750TWH/yr, largely situated off the western coasts of the Americas, Europe, Southern African and Australia/New Zealand.

The resource situated off the western coast of Ireland is deemed to be amongst the best in Europe, with an accessible resource of approximately 21TWH/yr (potentially more with technological advancement).

The wave resource off the coast of Northern Ireland is deemed to be *negligible.* This does not prevent the region from exploiting the burgeoning industry and firms/research centres have already significant developed expertise.

Tidal Energy

Two forms of tidal energy exist – tidal barrage and tidal stream – with the latter (the newer of the two) viewed as holding the most potential for development. Such development has begun (MCT's SeaGen prototype in Strangford Lough for example) but remains in its infancy.

Sustainable Energy Ireland (SEI) identified 11 costal areas in Irish Waters which hold potential for tidal stream development, four of which are specifically located off the coast of Northern Ireland.

Tidal Stream Resource (Irish Waters)

SEI estimates the **technical resource** available in Irish Waters to be **10.46TWH/yr** or 25% of the Single Electricity Market (SEM) demand for 2010 (42TWH/yr). This figure is revised down when physical constraints are factored in (offshore wave climate; military zones; shipping lanes; disposal sites; and outside areas containing pipelines and cables), giving the **practical resource** of **2.63TWH/yr** or 6.27% of the SEM's electricity demand in 2010.

The largest practical resource is Codling & Arklow Bank (0.791 TWH/yr). Northern Ireland's largest practical resource is the North East Coast (0.273 TWH/yr). The total practical resource in Northern Ireland waters is 0.530TWH/yr.

When issues of commercial viability are factored in the practical resource is further revised downwards, to **0.915TWH/yr** (2.185% of electricity demand). The majority of this resource is to be found in Northern Ireland's costal regions (in fact, Northern Ireland's practical resource is thought to be completely commercially viable). The North East Coast is considered to retain the largest **viable resource** (0.273TWH/yr), whilst **Northern Ireland's viable resource is 0.53TWH/yr,** 57% of the total viable resource in Irish waters (equivalent to 1.26% of the estimated energy needs).

The above figures were published in 2004, technological development since and in the future may result in these figures been revised upwards.

Tidal Stream Resource (UK Waters)

The Carbon Trust estimates the UK's theoretical tidal stream resource to be 120TWH/yr, of which 18TWH/yr are technically extractable. Only 12THW/yr are deemed to be economically extractable with a further 3TWH/yr thought to be economically extractable long-term.

A 2007 report, *Quantification of Exploitable Tidal Energy Resources in UK Waters,* estimates a *technically extractable* resource of 94TWH/yr is available in UK waters.

Ten UK sites were identified for possible exploitation over the next 5-10 years, with a combined *exploitable resource* of 4.3TWH/yr. Six of these sites are based in off the coast of Scotland representing 1.838TWH/yr. Two sites are found off the coast of Wales. They have a combined exploitable energy of 0.421TWH/yr. The largest single site has been identified off the coast of Alderney in the Channel Islands, and has an estimated exploitable tidal energy resource of 1.937TWH/yr. The remaining site is also situated around the Channel Island, specifically south of the Isle of White (0.161TWH/yr).

Tidal Stream Economics

SEI estimate tidal stream developments to have a capital cost of between €1700/kw and €3700/kw.

A recent academic study (2009), conducted by Trinity College Dublin, provides cost/benefit analysis of introducing tidal stream generation, with an installed capacity of up to 560MW, into the SEM. It concluded that at maximum penetration and running at full capacity, 560MW of installed capacity could *potentially* provide:

- an **emission saving** of up to €16m;
- a **fuel saving of** up to €40m;
- a **capacity saving** of up to €9m; and
- an increased **cycling cost** of €20m.

Based on these findings, and assuming an operation and maintenance cost of €55,000/MW per year (or €30.8m a year), the report concluded that for tidal generation to break even (at a 560MW level of installed capacity) capacity cost could not exceed €237,000 per MW installed. Currently, the cheapest conventional power plant has a capacity cost of €650,000 per MW installed.

Variability Issues

Whilst both wave and tidal stream generation are intermittent resources the Carbon Trust has concluded that the level of predictability is such that the network (as it is currently configured in the UK) could facilitate their inclusion. Tidal stream energy in particular was deemed to *“exhibit obvious, repeatable and predictable patterns of availability”.* The Carbon Trust also found the optimum level of tidal stream penetration was 10% of the energy mix, after which point *“the synchronised output of larger sites becomes more progressively dominant, increasing overall variability”* (and therefore further penetration became problematic).

Grid Issues

The capacity of the electricity grid to incorporate tidal stream energy and other renewables is cited as a significant obstacle to development.

System Operator EirGrid estimate that to ensure the SEM grid is fit for use in the future it will require investment of approximately €4bn.

Job Creation

The relative infancy of both tidal stream and wave energy development means that it is difficult to quantify the potential for job creation deployment might hold (currently 33 wave and tidal companies operate in the UK employing 629 people). Insights may be developed from the expansion of similar industries around the world however. For example the development of the wind industry has created *green collar* jobs globally – Germany employs 38,000 in the wind energy sector, Spain 20,500, and Denmark 17,000 – the range of jobs offered within the sector is wide, with high and low skilled opportunities available to workers in the numerous industries: manufacture; development; construction, operation and maintenance; utilities; and consultancy.

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Tables and Figures

1 Introduction

The following paper examines existing research into tidal and wave energy, focusing on resource availability, economic issues, variability, grid capacity and potential job creation.

Given the limited potential for wave energy waters off Northern Ireland's coast line the discussion of resource availability is weighted towards tidal stream resource potential. An overview of two papers examining potential supply in Irish and UK waters respectively is provided. Whilst both reports provide useful insight into the potential for tidal stream development and serve to contextualise the possibilities for development in Northern Ireland's coastal waters, direct comparison between the each paper's findings is problematic. Problems arise from the differing assumptions underlying each paper's methodology, not least the level of technological development achieved at the time of publication.

The information contained in the remaining sections has been derived from industry experts and academic research.

Throughout the paper the term *"Irish waters"* is used as a geographical term to refer to water off the coast of Northern Ireland and the Republic of Ireland within a 12 nautical mile territorial limit. The terms *"UK waters"* is used similarly to refer to the water off the coast of England, Scotland, Wales and the Channel Islands.

2 Wave Energy

The devices used to capture energy from the ocean's waves usually conform to one of three types:

- Overtopping devices, where the wave flows of a slopped barrier to fill a basin. The captured water is then pumped through a turbine to generate electricity;
- Oscillating water columns, where a device is placed part in water, part in air. As the wave passes over the device the air is displaced, turning an air turbine to generate power;
- Point absorbers, where the movements of a buoy are converted in mechanical or hydraulic power.[1]

Wave power generally increases the further offshore a device is located, making offshore devices, potentially, more cost effective. The cost of transmission and the engineering challenge increases the further offshore the energy is captured.[2]

[1] Rourke FO, et. Al. *Renewable energy resources and technologies applicable to Ireland*, Renewable, Sustainable Energy Review (2009) doi:10.1016/j.ser.2009.01.014 p6
[2] *Ibid* p7

2.1 Wave Energy Resource

The World Energy Council estimates that the economically exploitable global wave energy resource is in the region of 140-750TWH/yr (dependent on the current devices reaching technological maturity). They add, however, with potential improvements this could rise to as high as 2000TWH/yr. The majority of this exploitable resource is found in *"coasts with exposure to the prevailing wind direction"*, particularly the western coasts of the Americas, Europe, Southern Africa and Australia/New Zealand.[3]

Irish waters contain a substantial wave energy resource, particularly the west coast which reportedly has the *"best wave energy resource in Europe with annual average power levels of 76KW/m".*[4] A recent report by Sustainable Energy Ireland (SEI) puts the theoretical wave power resource available in Irish waters at 525TWh/yr. This theoretical resource, however, is constrained by a number of factors (institutional, planning or environmental constraints) leaving the accessible resource, which the report calculates to be 21TWh/yr.[5] This resource has, however, been calculated assuming levels of technical development current at the time of the report's publication (2005). Improvements in technological development should increase levels of accessible resource.[6]

Despite the large resource available in Irish Waters, Northern Ireland *"is sheltered from the North Atlantic swell"* and as a result *"the wave power resource in Northern Ireland is negligible"*.[7] The absence of an accessible resource off Northern Ireland's coast has not prevented the growth of a burgeoning wave energy industry in the region. Belfast based company, Pure Marine, has recently been awarded a grant from the Carbon Trust to develop its DUO WEC generator, which it could potentially export to the Republic of Ireland, Scotland and Australia.[8] Queen's University also has an established wave energy research facility, which is currently working on the Oyster wave energy converter (the project has so far received £2,360,000 in funding).[9]

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[3] World Energy Council *Survey of Energy Resources 2007* http://www.worldenergy.org/publications/survey_of_energy_resources_2007/wave_energy/760.asp

[4] Rourke FO, et. Al. *Renewable energy resources and technologies applicable to Ireland*, Renewable, Sustainable Energy Review (2009) doi:10.1016/j.ser.2009.01.014 p7

[5] Marine Institute & Sustainable Energy Ireland *Accessible Wave Energy Resource Atlas : Ireland* (2005) http://www.marine.ie/NR/rdonlyres/90ECB08B-A746-4247-A277-7F9231BF2ED2/0/waveatlas.pdf

[6] Rourke FO, et. Al. *Renewable energy resources and technologies applicable to Ireland*, Renewable, Sustainable Energy Review (2009) doi:10.1016/j.ser.2009.01.014 p7

[7] PB Power Ltd, for the Department of Enterprise, Trade and Investment *A Study into the economic renewable energy resource in Northern Ireland and the ability of the electricity network to accommodate renewable generation up to 2010* http://www.detini.gov.uk/cgi-bin/downutildoc?id=73

[8] Belfast Telegraph *Northern Ireland wave Energy firm closer to green dream* March 26, 2009 http://www.belfasttelegraph.co.uk/news/environment/northern-ireland-wave-energy-firm-closer-to-green-dream-14242560.html

[9] Queens University Belfast, School of Planning, Architecture and Civil Engineering, Environmental Engineering Research Centre, Coastal and Hydraulic Engineering (MRE) http://www.qub.ac.uk/research-centres/eerc/ResearchThemes/CoastalandHydraulicEngineeringMRE/

The main barriers to development of wave energy are viewed to be:

- under-developed technology, still in the demonstration phase;
- the extreme weather conditions which devices have to survive increase design costs;
- location drives up maintenance costs;
- grid access and connectivity.[10]

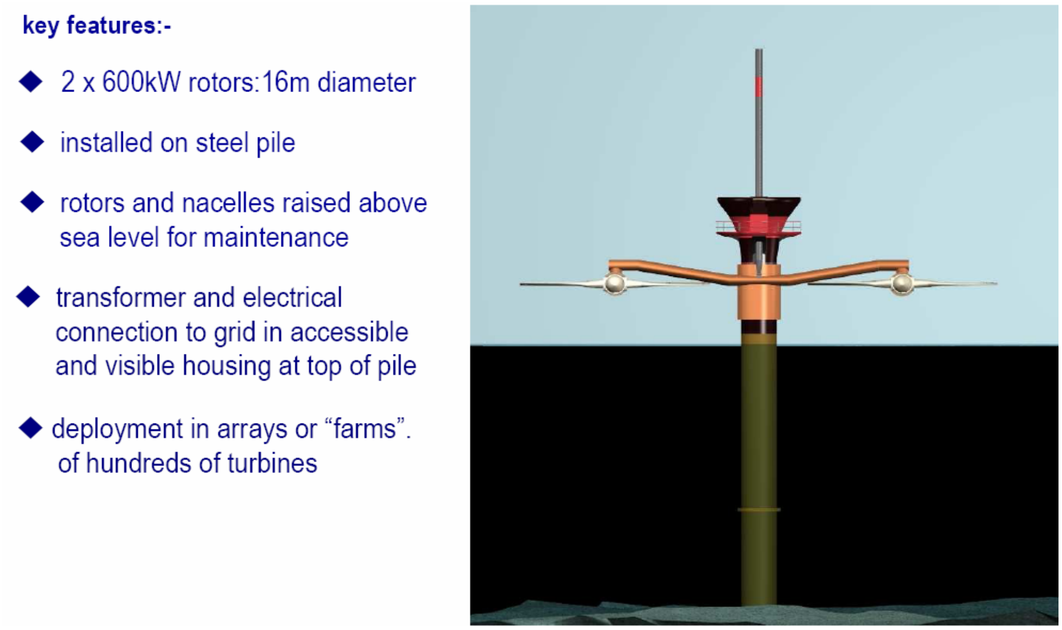
3 Tidal Energy

The simplest definition of tidal power is *"energy derived from movement of tides"*.[11] In practice, there are two forms of technology which exploit the energy potential of tides available – tidal barrages and tidal stream energy generation.
Tidal Barrage systems are the more established of the two technologies. They utilise a dam structure which impounds water at high tide, releasing it over a turbine to generate electricity as the tide ebbs. The largest tidal barrage has operated at La Rance, France for around forty years and provides, on average, a typical yearly output of 0.5TWhs.[12] The Severn Estuary has been proposed as a potential site for a similar power station in the UK. Studies on the site have been ongoing since the 1970s but development has been unsuccessful (due to cost and environmental concerns). An inquiry into the estuary's potential, which concluded April 2009, rejected development plans on the basis a project, would *"do serious damage to the estuary by wiping out around 80% of the 'inter-tidal habitat'"*. The same inquiry recommended the construction of a smaller barrage system on the estuary and also encouraged research into energy storage.[13]

Tidal stream energy generation utilises underwater turbines (similar to, but smaller than, wind turbines) to exploit the energy resulting from tidal currents (flows of water created as tides flow in and out of estuaries and between channels).[14]The SeaGen Technology, in place at Strangford Lough (see Figure 1), provides one example of the how the technology operates. The technology has an installed capacity of 1.2mw, which could power around 1,000 households. Estimates place the cost of the project at £12m.[15]Project developers, MCT received a BERR grant of £5.2m and £500,000 of financial assistance from Northern Ireland Electricity.[16]

[10] Rourke FO, et. Al. *Renewable energy resources and technologies applicable to Ireland*, Renewable, Sustainable Energy Review (2009) doi:10.1016/j.ser.2009.01.014 p7
[11] Energex *Glossary* http://www.energex.com.au/switched_on/glossary.html (accessed 20/04/09)
[12] *Ibid* p975
[13] BBC *Severn's tidal barrage rejected* (April 2009) http://news.bbc.co.uk/1/hi/england/bristol/8001407.stm (accessed 20/04/0
[14] Brewster P, *Marine Renewables: the race is on* Northern Ireland Link – Environmental Fact Sheet *Climate Change: the energy issue* March 2008 p36
[15] The Belfast Telegraph, World's first as £12m turbine installed in Strangford Lough, March 31 2008
[16] The Irish News, NI Tidal power turbine blades damaged, July 22 2008

Figure 1: SeaGen Prototype



3.1 Tidal Stream Energy Resource

There is potentially substantial capacity for the application of tidal stream energy in the UK and Ireland. Sustainable Energy Ireland (SEI) has published an extensive study (2004) on the potential energy source available in Irish waters. ABP Marine Energy Research, on behalf of the UK government, has published a *"Quantification of Exploitable Tidal Energy Resources in UK Waters",* a paper which examines secondary and primary research. This section provides an overview of these papers.

3.1a Tidal and current resources in Irish Waters

Table 1 outlines the potential exploitable tidal resource in Irish Waters. The table is based upon the tidal resources found at 11 coastal areas around the Island of Ireland, namely:

- Inishtrahull Sound;
- Lough Foyle;
- North East Coast;
- Ram Race Copeland Island;
- Strangford Lough;
- Codling & Arklow Banks;
- Tuskar Rock & Carnsore Pont
- Gascanane Sound;
- Dursey Sound;
- Shannon Estuary;
- Bulls Mouth.[17]

[17] Sustainable Energy Ireland *Tidal and Current Energy Resources in Ireland*

The five resource categories found in the table allow comparison of the theoretically extractable with the actual extractable resource (given present limitations). Each of the categories is explained below, providing an insight into the restrictions to full exploitation of maximum tidal power. The figure for percentage electricity consumption is based upon an estimated combined total electricity usage of 42TWH/per year for Northern Ireland and the Republic of Ireland. Annex A demonstrates the varying intensity of peak spring tidal currents, whilst Annex B shows the geographical location of the 11 sites listed above.

The term **theoretical resource** refers to the *"gross energy content of tidal and marine currents"* in a given area. The figure given for total theoretical resource is determined by applying computational modelling to current flows found in Irish waters. As is evident from the table if it was possible to exploit each of the 230TWH/yr theoretical resource tidal energy could provide 5-6 times the expected electricity consumption for Northern Ireland and the Republic Ireland in 2010.

The figures provided for **technical resource** are calculated using a similar method to that of theoretical resource, except that areas with peak tide velocities below 1.5m/s have been excluded. The figure for technical resource also assumes a device efficiency of 39% and that technical restriction, such as water depth, can be overcome. The results show a much smaller exploitable resource (10.46TWH/yr), although one still able to provide 25% of electricity to Northern Ireland and the Republic of Ireland. An important aspect of the study's findings here is the assumption that:

> *"..tidal systems are in their infancy and there have been only a small number of prototype scale demonstrations of plant with an installed capacity of over 100KW."*

Given the date of the study this is to be expected, it is evident that there has been considerable development in the years since its completion. The SeaGen prototype, for example, has an installed capacity of 1.2MW. However, the SEI study makes allowances for possible technological improvements, assuming that first generation tidal farms will have an installed capacity of 1MW to 25MWs, featuring individual turbines of 0.25MW to 1MW capacity. The 10.46TWH/yr figure factors this assumption in.

The available technical resource is further constrained by practical and physical factors, such as: suitability for base structures; offshore wave climate; military zones; shipping lanes; disposal sites; and outside areas containing pipelines and cables. Consideration of these factors, as well as the previously outlined technical factors, delivers a resource estimate referred to as the **practical resource**. Figures for the practical resource show total resource of 2.63TWH/yr, providing 6.27% of electricity. Table 2 outlines the practical resource exploitable for each of the 11 sites listed above. The table shows the largest practical resource is Codling & Arklow Bank (0.791 TWH/yr). Looking specifically at Northern Ireland's waters, the largest practical resource is the North East Coast (0.273 TWH/yr). The total practical resource in Northern Ireland waters is 0.530TWH/yr.

The **accessible resource** is the practical resource further constrained by *"man-made, institutional and regulatory"* factors. Such factors might include health and safety, planning and environmental regulations. Specific site development will be precluded by environment assessments, as such the figure in table 1 have not been adjusted to include the various constraining factors which separate accessible and practical resources.

The **viable resource** is the practical resource further constrained by commercial viability, factors such as: development cost; scale; resource distribution; market reward; timing; and other risks.

In the determining the viability of the selected sites, the SEI study examined each individually to establish the most suitable turbine array. The MCT Seaflow device, a precursor to the MCT SeaGen model (outlined above), was used as the base technological device in developing a techno-economic model for each site. The model takes into consideration physical constraints and financial and operational assumptions. The physical constraints factored into the techno-economic analysis include:

- a minimum water depth of 20m, so that a minimum rotor diameter of 15m can be accommodated;
- a maximum water depth of 40m;
- a mean maximum spring tide current velocity exceeding at least 2m/s;
- distance to the shore/grid connection;
- turbine rotor size was chosen to suit water depth.

The financial and operational assumptions underlying the calculations were as follows:

- a Discounted Cash Flow rate of 8% over 20 year life span;
- insurance premiums and sea bed rental costs were included and based upon UK experience;
- machine availability is assumed to be 90%, equating to a downtime of one month in twelve. The difference in downtime for exposed locations, compared to less exposed locations, is not included;
- foundation costs – site investigation, licences, environmental assessment, design, onshore/offshore transport, seabed preparations, installation, cable laying, etc – were included;
- indicative grid costs, accounting for variation between sites, were included;
- operation and maintenance (O&M) costs of 2% - 5% of total energy cost, dependent upon the number of devices in a specific farm, were included.

In addition to the above, the turbine model was optimised for each specific site by selecting a *“rated velocity which minimises the cost of generating electricity”.* Establishing an optimum turbine model allows for energy capture is calculated, which is then reduced to allow for 90% machine availability. With reference to all of the above, capital investment (ranging from €1700/kw in the Shannon Estuary to €3700/kw at the Codling Bank) and unit cost (ranging from 10 cent/KW to 20 cent/KW) can be calculated.

All of the above must read in the context of a new and developing technology, which in 2004 cost *"approximately 25% in real terms of its cost when generated 20 years ago".* At the time of writing (2004), the SEI assumed costs would decrease 50% - 75% with technological improvements. Moreover, it is evident that there have been significant technological improvements between the publication and the contemporary market position (this is apparent in the study's use of MCT Seaflow turbine which has been superseded since publication). Furthermore, the projects proposed by the study are relatively small (10MW), with cost expected to decrease significantly as technological penetration increase.

However, with the above in mind, the study concludes that the viable energy resource in Irish waters is 0.915TWH/yr or 2.18% of electricity need. Table 3 lists each site by their viable resource. It is evident from the table, once the cost of development is considered; the North East coast becomes the most viable site in Irish waters. It is notable that for each site in Northern Ireland waters the practical resource matches the viable resource. As such, Northern Ireland's viable resource is 0.53TWH/yr, 57% of the total viable resource in Irish waters. This is equivalent to 1.26% of the estimated energy needs of Northern Ireland and the Republic of Ireland in 2010.

Table 1: Tidal Energy Resource in Irish Waters as percentage of Electrical Consumption

Resource Category	**Resource Total TWH/yr**	**% Electrical Consumption (2010)**
Theoretical	230	500
Technical	10.46	25
Practical	2.63	6.27
Accessible	2.63	6.27
Viable	0.92	2.18

Table 2: Practical Tidal Energy Resource by Site

Site	Total Resource GWH/yr
Inishtahull	514
Lough Foyle	2
North East Coast	273
Ram Race Copeland Islands	125
Strangford Lough	130
Codling & Arklow Banks	791
Tuskar Rock & Carnsore Pont	420
Gascane Sound	1
Dursey Sound	4
Shannon Estuary	367
Bulls Mouth	6

Table 3: Viable Tidal Energy Resource by Site

Site	Total Resource GWH/yr
Inishtahull	16
Lough Foyle	2
North East Coast	273
Ram Race Copeland Islands	125
Strangford Lough	130
Codling & Arklow Banks	70
Tuskar Rock & Carnsore Pont	177
Gascane Sound	1
Dursey Sound	4
Shannon Estuary	111
Bulls Mouth	6

3.1b Tidal Stream Resource in the UK

A 2004 report commissioned by the Carbon Trust estimated the *known* non-European global tidal resource to be up to 120TWH/yr. The UK's total resource was calculated to be 110THW/yr, of which up to 18TWH/yr were *technically extractable* (equivalent to 5% of UK energy needs). Technically extractable refers to the level of resource that can be harnessed without significant environmental or economic impact. The report adds that of this resource, 12TWH/yr could be economically extractable, of the remaining 6TWH/yrs, 3TWH/yr are likely to economically exploitable in the longer term.[18]

In 2007 consultancy firm ABP Marine Environmental Research (ABPmer) conducted a study (*Quantification of Exploitable Tidal Energy Resources in UK Waters)* which

[18] Black Veatch, for the Carbon Trust *Tidal Stream Energy – Resource and Technical Summary Document* (2004)

contains an assessment of areas suitable for development, an overview of potential constraints, and estimation of the *technically extractable* and *exploitable* tidal energy available in UK waters.

The study assumes, for purposes of calculation, marine current devices with an installed capacity of 5MW and wind farms with an installed capacity of 5-30MW/km^2 (it is assumed that individual site may be home to a number of farms).[19] Based on these assumptions the study calculates a *technically extractable* resource of 94/TW/yr. *Technically extractable* refers to the amount of exploitable energy from areas that are suitable for technological deployment and are free from *exclusion constraints* (proximity to oil and gas pipelines, ammunition disposal sites, anchorage sites and so forth). To achieve such a yield, given the current stage of technological development, would require deployment of approximately 200,000 devices across 11,000km. The study clarifies[20]:

> *"These results are therefore presented as a reference to the technically achievable maximum energy yield, should political, economic, and grid connection issues allow all areas of good tidal resource to be developed for energy extraction."[21]*

The study continues to develop a picture of the exploitable tidal energy resource which will be available over the next five to ten years. The report examines the 50 best *cells of tidal resource* which fall into ten geographical areas (Table 4 provides a full breakdown of these areas, the potential tidal stream device deployment and energy yields of each). Retaining the 30MW limit on tidal farms (although with more than one farm per site), exploitation of these ten areas could result in an installed capacity of 1,500MW with the potential to generate 4.3TWH/yr. Of the top ten sites 6 are based in off the coast of Scotland representing 1.838TWH/yr or 42.2% of the total resource found at the selected sites. Two sites in the top ten are found of the coast of Wales. They have a combined exploitable energy of 0.421TWH/yr, equal to 9.7% of the total exploitable source at the selected sites. The largest single site has been identified off the coast of Alderney in the Channel Islands, and has an estimated exploitable tidal energy resource of 1.937TWH/yr or 44.5% of the total exploitable resource found at the top ten sites. The remaining site is also situated around the Channel Islands, specifically south of the Isle of White. This has an exploitable yield of 0.161TWH/yr, or 3.2% of the total exploitable resource at the selected sites.

The study's estimates assume a 100% uptime; as a result the actual level of electricity generation is likely to be slightly lower, due to planned and unplanned maintenance. The report also acknowledges that *"the cumulative effects of energy removal by successive 30MW rated arrays in confined areas of tidal resource, and also grid connection issues, may provide a potential barrier to the deployment of such large capacities".* Despite this, the report remains optimistic that such large yields will be made possible through technological development.[22]

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[19] ABP Marine Environmental Research *Quantification of Exploitable Tidal Energy Resources in UK Waters* (2007)http://www.abpmer.co.uk/files/report.pdf p4
[20] *Ibid* p5
[21] *Ibid*
[22] *Ibid*

Table 4 Exploitable Resource at top ten tidal stream sites in UK Waters

Location	Number of Cells	Area (km2)	No of Devices Deployed	Installed Capacity (MW)	Annual Energy Yield TWH/yr
Adlerney Race	22	63	204	660	1.937
West Islay	7	21	112	210	0.584
South Pentland Firth	6	16	61	180	0.555
Anglesey	3	9	47	90	0.238
Ramsey Island	2	6	35	60	0.183
North Pentland Firth	2	5	17	60	0.181
SW Islay	2	6	30	60	0.179
Westray Firth	2	5	13	60	0.177
Pentland Skerries	2	5	20	60	0.162
South Isle of Wight	2	6	30	60	0.161
Total	**50**	**142**	**569**	**1500**	**4.357**

3.2 Tidal Stream Energy Economics

As outlined above the SEI study estimated capital costs for tidal stream development could range from €1700/kw in the Shannon Estuary to €3700/kw (based on 2004 prices), whilst O&M costs where deemed to be equal 2% - 5% of total energy cost, dependent upon the number of devices in a specific farm. At the lowest point in the capital cost range the THETIS proposals for Torr Head, for a 100MW to 200MW tidal stream farm's capacity cost would be between €170m and €340m. At the higher point of the range the capital cost would be between €370m and €740m.

A more recent and thorough examination of tidal stream economics has been carried out by the department of economics at Trinity College Dublin, who have conducted a cost/benefit study into the technology utilising the same software previously used to model the Single Electricity Market. The software, adapted to include tidal energy, ran for an entire year with increasing penetrations of installed tidal generation periodically introduced (up to 560MW of installed capacity).[23] The results were then evaluated to determine the emissions savings benefits, fuel saving benefits, capacity benefit and cycling costs.

Emissions savings – the study found that as tidal generation replaces conventional generation the *system emissions of CO_2, SO_2 and NO_x are reduced.* However the study found that such reductions where modest. The study maintained that the relatively low load factor of tidal stream energy, 22%, which results in *"a smaller reduction in conventional generation output than a similarly sized unit with a higher load factor".* Figure 2 demonstrates the value of emissions savings in monetary terms.[24] The graph shows a direct correlation between increased tidal stream penetration and the monetary value of emissions savings, running at full capacity 540MW of tidal stream power would

[23] Denny E, *The Economics of Tidal energy* (2009) Energy Policy 37 pp1917 – 1924 Elsevier Ltd.
[24] EDR refers to Electrical Down Rating, EDR 40% means turbines are downgraded to 40% of the running capacity, there 540MW installed capacity runs at 336MW

result in emissions saving in excess of €16m. Figures are calculated on the basis of EU price of CO_2 (€30/t), and the US saving price of SO_2 (€150/t) and NO_x (€3000/t).[25]

Fuel savings – due to the limits the study placed on tidal stream penetration (6% of all installed capacity), the fuel savings were found to be *"modest".* Despite this the study found concluded that (based on the current generation mix in the SEM) result in a 5m gigajoule (GJ) reduction in gas consumption (approx 3% of the current total) and a 2m GJ reduction in oil consumption (approx 19% of the current total). Figure 3 shows these saving translated into monetary value, results are calculated using 2008 prices for the cost of specific fuels per GJ (NI prices converted to Euro at 2008 rates). It is evident, at the maximum penetration envisaged by the study (running at full capacity) tidal stream penetration could save approximately €40m in fuel costs.[26]

Capacity Benefit –refers to the extent to which tidal generation can be a substitute to conventional generation without reducing the reliability of the overall system. The variability of tidal stream energy adds complexity to the relationship between it and conventional sources of generation, as *"it may not necessarily be the case that times of high tidal energy coincide with times of high demand".* The capacity credit of tidal stream energy ranges from 25% at low capacity to 15% at 540MW. Tidal streams capacity credit can be viewed as a benefit as it reduces the costs of building and maintaining conventional generation plants that have a capacity credit equal to that of the installed tidal stream plants. The study assumes that new conventional capacity within the SEM will be gas fired and have capital cost of €65,000 per MW and an O&M cost of €45,000 per MW per year. Figure 4 shows the monetary value of saved investment in conventional generation tidal stream penetration will enable, totalling approximately €9m at 560W penetration.[27]

Cycling Costs – refers to additional O&M costs associated with the day to day process of cycling conventional generations systems in order to meet demand (ramping systems up and down or turning them on and off as required). It conventional systems the costs are estimated to be between €200 and €500,000 per single incidence of turning a generator on and off. Greater tidal penetration increases the incidence turning generators on and off (as demonstrated in Figure 5). The study estimated that this would equate to a cost in excess of €20m at 560MW penetration at full capacity (Figure 6).

Break/even analysis – the Trinity paper states:

> *"Since tidal generation is still in its infancy clearly defined capital costs have not yet been established and forecasting the likely capital costs could be erroneous. In addition, there have been no comprehensive network reinforcement studies completed for Ireland with respect to tidal generation."*

However, the study calculates the net benefit of 540MW of installed capacity at €46.1m. That total emissions plus fuel savings plus capacity benefit minus cycling costs. By assuming and O&M cost of €55,000/MW per year[28] (a total of €30.8m) the study

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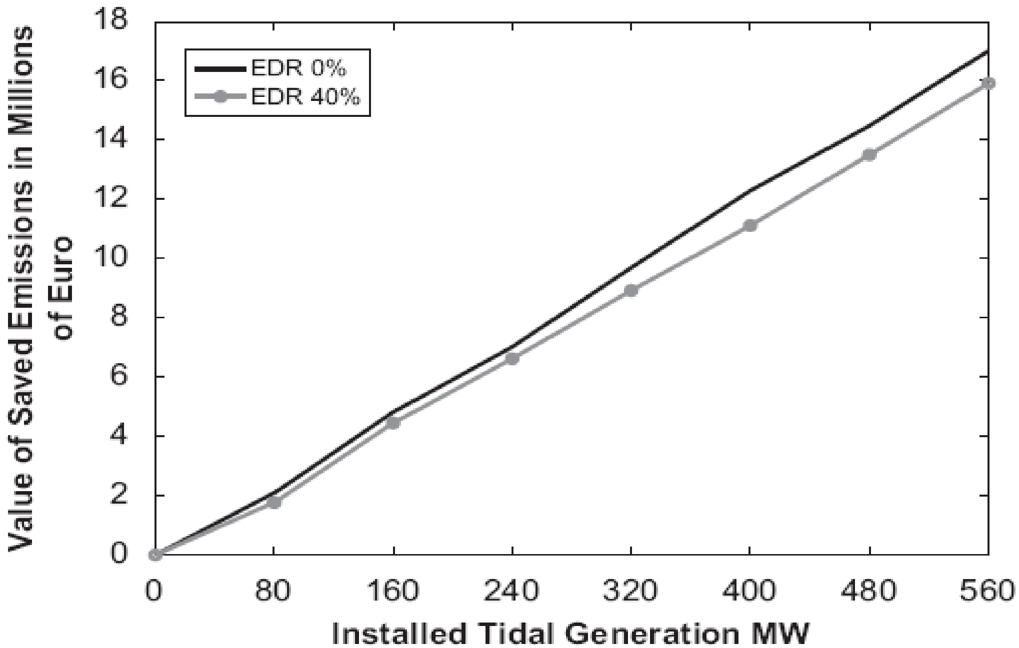
[25] *Ibid*
[26] *Ibid*
[27] *Ibid*
[28] Less than O&M for offshore wind, offshore O&M cost *"tend to be high given accessibility issues and greater infrastructure costs*

calculates the breakeven capital cost of tidal stream generation €15.3m (assuming no network reinforcement). In other words, according to the study, for 540MW tidal stream penetration be to economically beneficial its capacity cost could not exceed €237,000 per MW installed (this is deemed to be greater at lower levels of penetration €510,000 at 80MW penetration, see Table 4). This is contextualised by comparison with the cheapest available conventional generation plant which has a capacity cost of €650,000 per MW installed.[29]

Figure 2: Monetary value of emissions savings from tidal stream



[29] Denny E, *The Economics of Tidal energy* (2009) Energy Policy 37 pp1917 – 1924 Elsevier Ltd

Figure 3: Monetary value of fuel savings from tidal stream

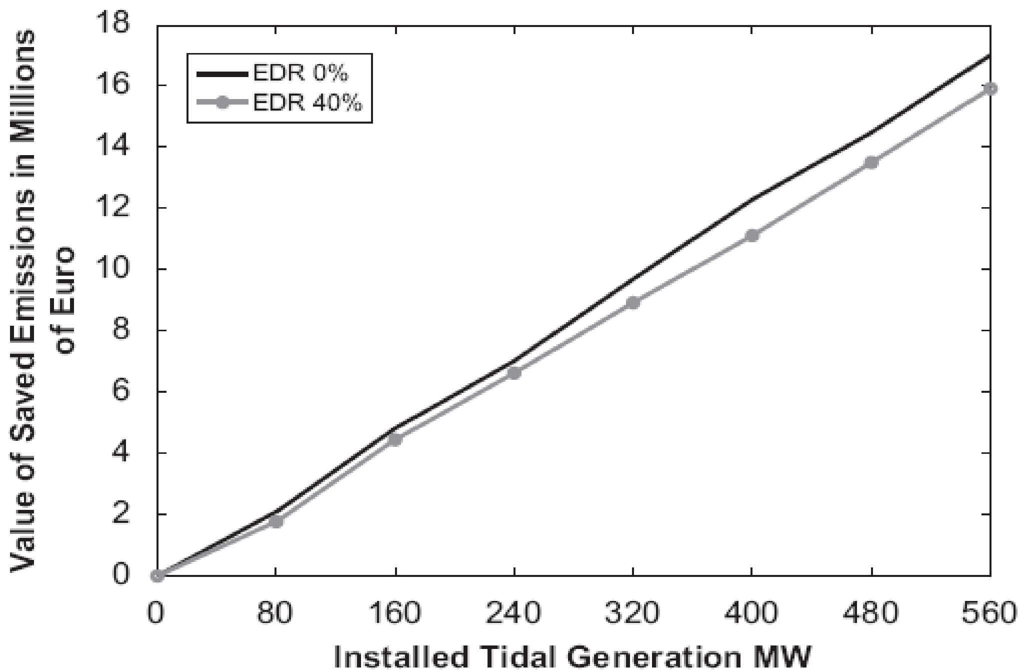


Figure 4: Monetary value of investment savings in conventional generation

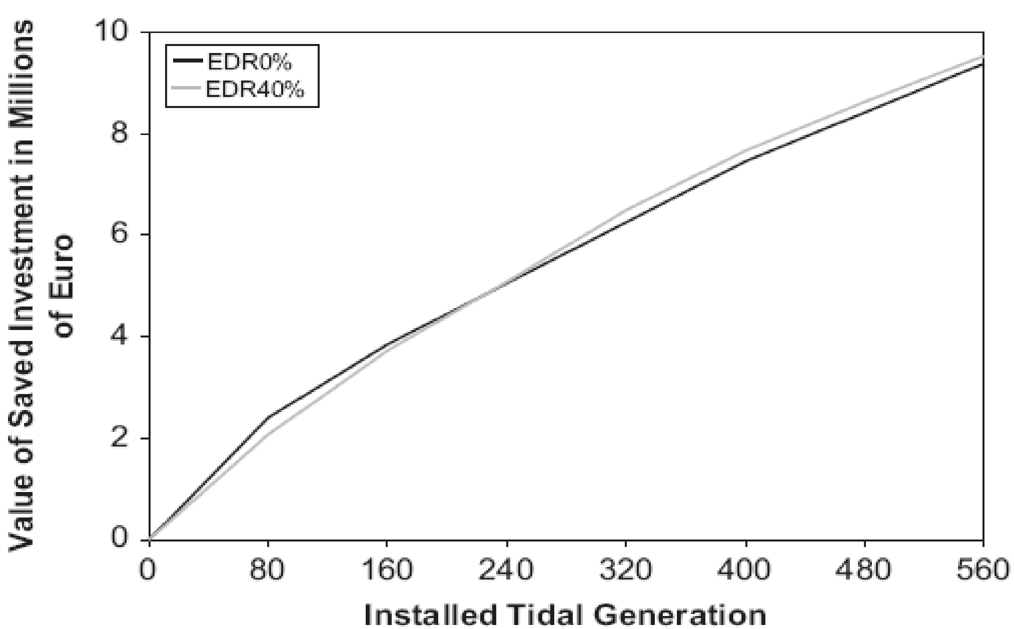


Figure 5: Impact of tidal generation on the number of conventional stop/starts

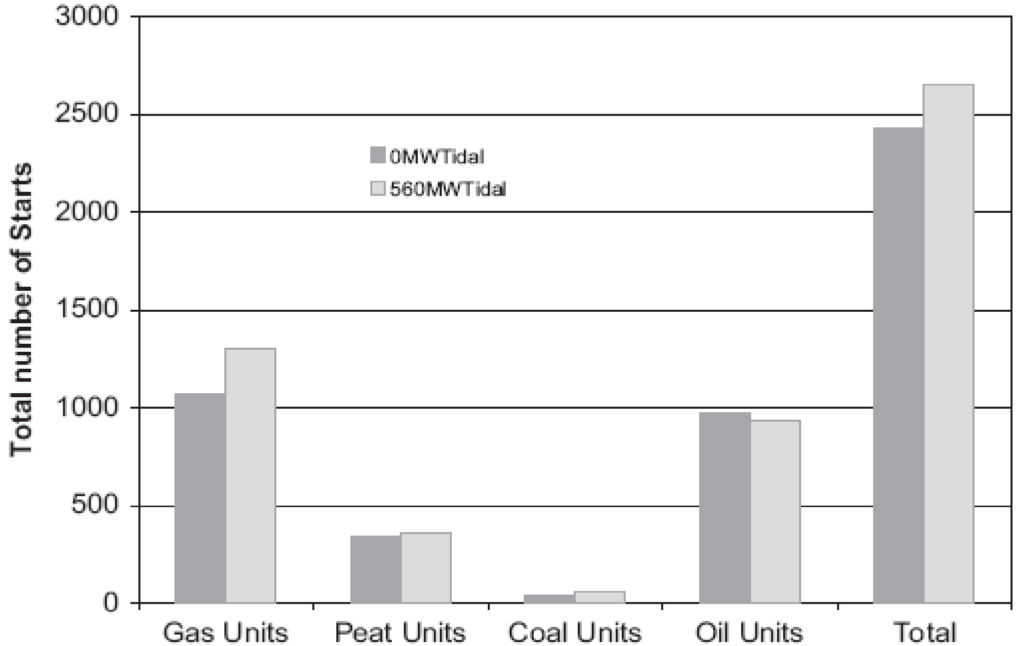
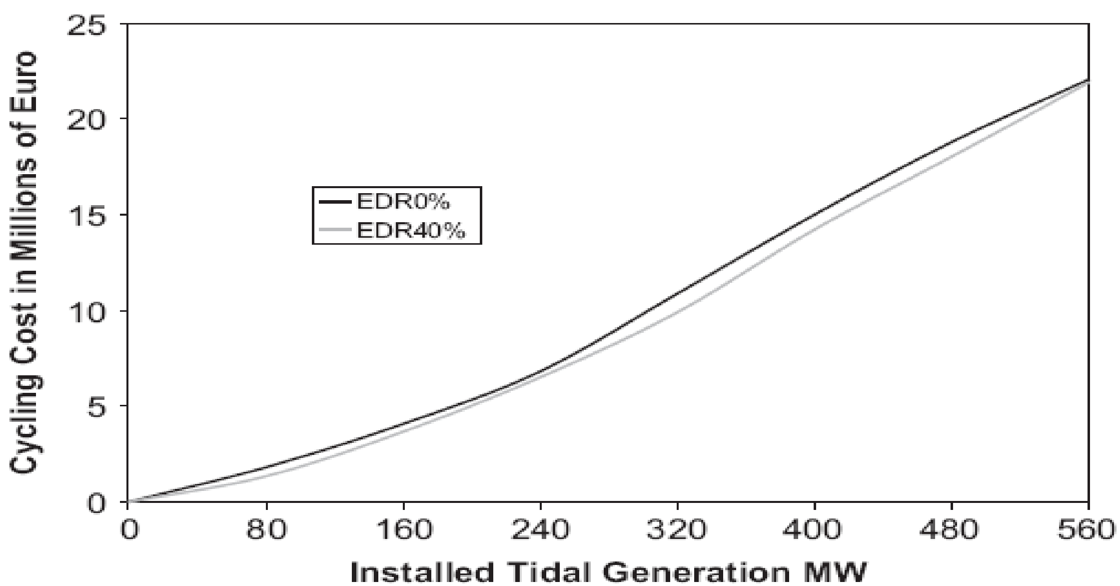


Figure 6: Monetary value of cycle costs



4 Variability Issues

The Carbon Trust has assessed the variability issues associated with both wave and tidal stream generation; by examining the characteristics of each resource in a UK context (it is assumed that the findings are transferable).

With regard to **wave energy** the report found:

- all regions examined showed high seasonality, with *"average monthly wave power availability up to seven times higher in winter than summer"*; and
- wave power delivers, on average, five times more energy during periods of peak electricity demand than periods of low demand;
- hour to hour variability of the UK wave resource is low in comparison to the tidal resource;
- at high energy wave sites there is a degree of stability in the energy delivered by wave energy overtime, in other words *"the most likely output in the next hour is similar to that being delivered in the current hour"*;
- diversifying wave generating capacity over a number of high energy wave sites reduces variability, particularly during winter;
- the pattern of wave power is not random and can be predicted.

With regard to **tidal energy** the report found:

- tidal currents *"exhibit obvious, repeatable and predictable patterns of availability"* that are site specific;
- the power output at individual sites rises to a peak and falls to a minimum (approaching zero) approximately four times a day. The timing of this variation *"is site specific and predictable"*;
- the overall level of variability is dependent on specific site development and the level of general development;
- sites with smaller generation and development potential are important in *"smoothing within day variability, as maximum and minimum out levels at these site occur at different times to the larger resource sites"*;
- a 10% penetration rate will result in low levels of daily variability, above 10% *"the synchronised output of larger sites becomes more progressively dominant, increasing overall variability"*;

Overall the report found that tidal power variability has a limited impact on net electricity demand. Patterns of tidal power availability do not mirror electricity demand patterns –

there are times when peak availability matches peak demand, and times when peak demand occurs during minimum availability – the Carbon Trust argue that *"this changing relationship tends to balance out some of the variability impacts on net demand".* Given current estimates of UK tidal energy generation of 5% and the above outlined 10% cut off point, the Carbon Trust concluded at this level of penetration the *"variability in the tidal current is limited in comparison to demand levels".*

A recent academic study adds to the debate with the following statement:

> *"…despite it's predictability, tidal generation output is still variable and non-dispatchable in nature and as such poses a challenge for system operators. An increase in variable generation on an electricity system may result in an increase in the cyclical operation of conventional units as system operators attempt to coordinate the following of functional demand throughout the day and the variable output of the tidal generation. An increase in the cycling of conventional units can result in increased wear and tear on the machines and result in shortening of the life span of the units.[30]"*

The implication here is that increased tidal penetration (or penetration of any variable resource for that matter) may raise operation and maintenance cost for conventional plants, and could potentially necessitate their replacement much earlier than planned.

5 Grid Capacity Issues

The capacity of the electricity grid to incorporate tidal stream energy and other renewables is cited as a significant obstacle to development.[31] Summarising the situation system operator EirGrid has stated:

> *"Capacity has remained largely unchanged in the last 20 years, a period that has seen a growth of 150% in the electricity demand being carried by the system… to facilitate the necessary increase in renewable generation and to adequately meet the demands of the electricity customer, the capacity of the bulk transmission system will need to be doubled by 2025."[32]*

The company estimate that to ensure the SEM grid is fit for use will require investment of approximately €4bn. Such levels of investment would:

- provide approximately 1,150 km of new circuits (representing an increase of about 20% on the total length of the existing network), 800 km of which will be at 220 kV or higher; the other 350 km at 110 kV. In addition to these circuits, others will be needed to connect many of the new generators to the Grid; and

[30] Denny E, *The Economics of Tidal energy* (2009) Energy Policy 37 pp1917 – 1924 Elsevier Ltd.
[31] Rourke FO, et. Al. *Renewable energy resources and technologies applicable to Ireland*, Renewable, Sustainable Energy Review (2009) doi:10.1016/j.ser.2009.01.014 p8
[32] EirGrid *Grid 25* http://www.eirgrid.com/EirgridPortal/uploads/Announcements/EirGrid%20GRID25.pdf

- upgrade 2,300 km of the existing transmission network to provide greater capacity. This includes 1,100 km or 70% of the existing 220 kV network and 1,200 km of the 110 kV network.

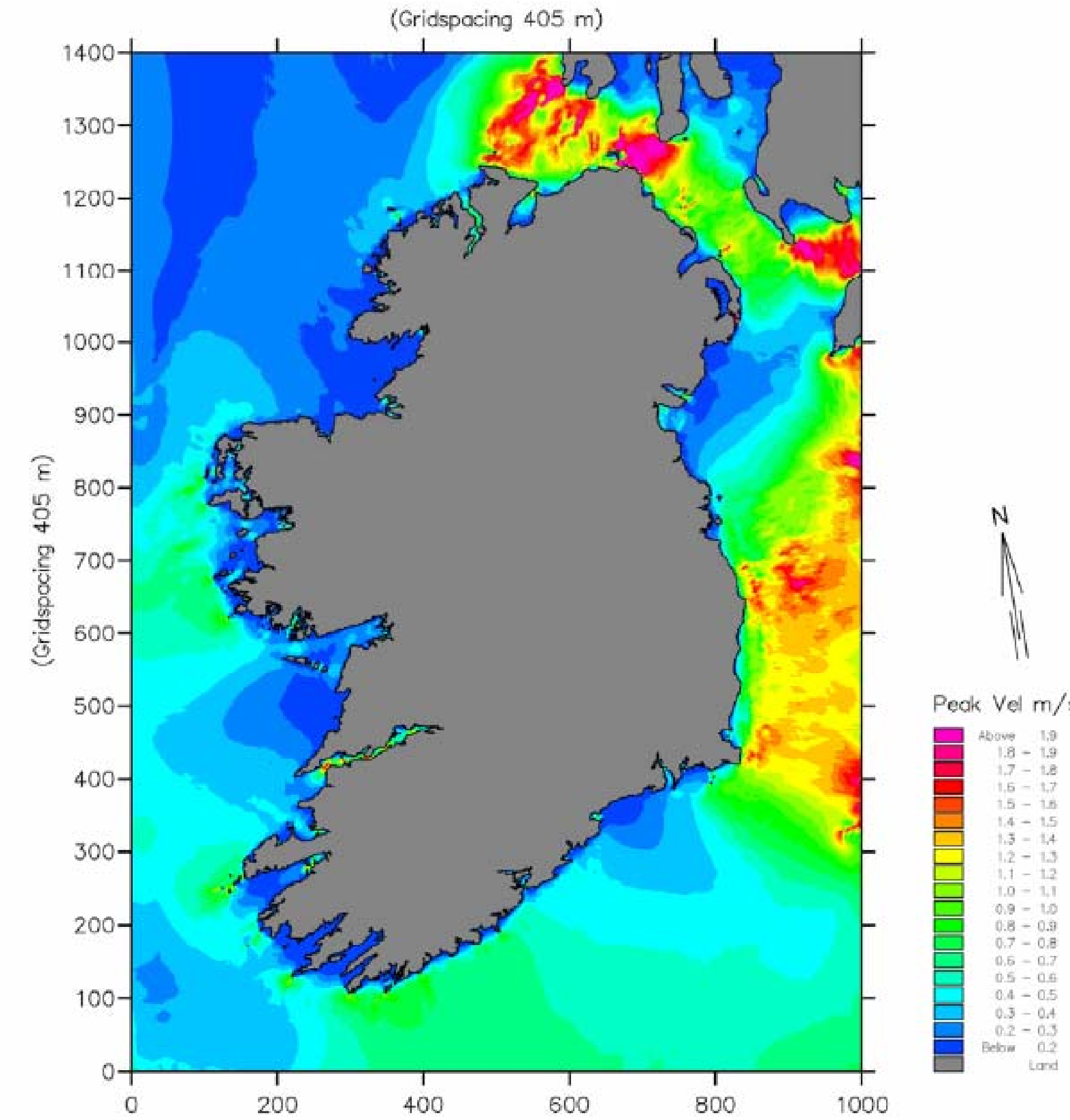
6 Job Creation Potential

Tidal stream and wave power generation, as markets, are in their relative infancy, there are currently 33 wave and tidal companies operating in the UK, employing 629 people.[33] At this stage of their development it is not possible to say how their introduction might affect the job market. It is possible, however, to draw comparisons with globally established renewable industry. A co-authored Institute for Public Policy Research/Greenpeace report (April 2009), for example, examines the wind energy markets in Spain, Denmark and Germany, and estimate that development of offshore wind farms could create in the region of 23,000 to 70,000 jobs in the UK depending on the size of the resource installed. They suggest that there is no *guarantee that all of the jobs would be located in the UK*, especially since components for existing farms are currently imported, but add that the skill and knowledge base to develop this particular renewable technology exists within the UK, particularly within the manufacturing sector.[34]

The development of the wind industry has created *green collar* jobs around the world: Germany for example employs 38,000 in the wind energy sector; Spain 20,500; and Denmark 17,000. The range of jobs offered within the sector is wide, with high and low skilled opportunities available to workers in the numerous industries: manufacture; development; construction, operation and maintenance; utilities; and consultancy.[35]

[33] BERR *Low Carbon and Environmental Goods and Services: an industry analysis* 2009 Innovas Solutions
[34] IPPR/Greenpeace *Green Jobs: Prospects for creating jobs from Offshore Wind in the UK* (2009)
[35] Wind Energy – The Facts *Part three: Economics of Wind Power* http://www.wind-energy-the-facts.org/en/part-3-economics-of-wind-power (accessed 14/01/09)

Annex A Depth Average Peak Spring Tidal Currents



Annex B Potential Tidal Development Site