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Developments within the UK Wave Energy Sector

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Abstract

The UK's wave energy sector is at a crucial pre-commercial stage of development attempting to transition from prototype/demonstration phase of maturity towards a larger scale revenue supported industry. A host of advantages that could be realised through the successful commercialisation of the sector include; the potential within the UK to generate 40-50TWh/yr and (along with tidal technology) both £3.7bn worth of export, and the over 10,000 jobs by 2020 (RenewableUK, 2012, House of Commons Energy and Climate Change Committee, 2012, RenewableUK, 2010). Despite this, strong criticisms have been made about the commercialisation process, including; a lack of coordination between funding bodies, limited communication between universities and industry and an overly centralised base of key actors (House of Commons Energy and Climate Change Committee, 2012, National Audit Office, 2010, EPSRC, 2009, Renewables Advisory Board, 2008, Winskel *et al.*, 2006). Although the value of strong problem solving networks has been noted, problems arise in assessing these networks, including validating the presence, nature and value of relationships as well as the identification of more tacit and informal linkages (Hekkert and Negro, 2009, Freeman and Soete, 2007, OECD, 2005, Håkansson, 1990). In this paper, Bergek *et al*'s Technology Innovation Systems is used in conjunction with network analysis to validate and explore these criticisms as well as provide a narrative insight into the sectors current activities (Bergek *et al.*, 2008a). It is shown that although high levels of interaction are occurring (particularly within the academic community), what Jacobsson *et al* describe as *prime movers* are present and less mature device developers are effectively isolated from the system as it develops norms and practices (Jacobsson and Johnson, 2000). This, combined with a process of government *gating* (i.e. effectively picking technology winners) has led to a *Mathew Effect* between developers whereby some have access to finance and are shaping institutional norms while others struggle. Although convergence is to be expected as the industry matures, lack of public sector coordination, transparency of the decision making process and comparability between devices has reduced both investor and stakeholder legitimacy in the sector.

Keywords: *Wave Energy, Network Analysis, TIS, Innovation, Support Gating*

Introduction:

There have been a wide range of public, academic and industry led studies over the last decade into the potential benefits and opportunities of commercialising marine renewable energy within the UK. These benefits fall roughly into two categories; technical, and economic. Technically, the waters around the UK are considered to be among the best in the world as a source of wave energy and could be used to provide 40-50TWh/yr of electricity, helping to meet our wider CO_2 reduction targets (House of Commons Energy and Climate Change Committee, 2012, Committee on Climate Change, 2011, Renewables Advisory Board, 2008). Although more erratic then tidal energy, wave energy availability within the UK should produce on average an estimated five times more energy during peak demand than periods of low demands, have lower levels of hour-to-hour variability and accurate predictability up to several days in advance. (POST, 2009, Carbon Trust and Environmental Change Institute, 2005, The Science and Technology Committee, 2001). From a deployment perspective, low levels of availability variation between different device types means that devices are substitutable on larger arrays and therefore technology 'lock-in' is less of an impending problem (Carbon Trust and Environmental Change Institute, 2005). Additionally, since wave technologies are incrementally deployed, (unlike nuclear or other centralised generation technologies) environmental monitoring and cost assessments can be done concurrently with deployment as capacity ramps up, producing a lower risk profile.

Along with these factors, there are several other strong economic considerations for supporting wave energy technology: the long term value to the UK (for wave and tidal technology combined) is estimated to be in the region of £6.1bn per annum, while export potential alone could be as high as £3.7bn by 2020 (House of Commons Energy and Climate Change Committee, 2012, RenewableUK, 2010). It is also estimated that as many as 16,000 UK jobs could be created within the wave energy sector by the 2040s (Carbon Trust, 2009a).

Finally, the UK has a significant historical advantage over many nations, with experience not only within offshore marine engineering, but a long history of marine renewable energy research. This has resulted in a high number of device developers and some of the world's current leading research institutes in the sector (Entec UK Ltd, 2009, Douglas-Westwood, 2008, Winskel *et al.*, 2006).

The sector has nonetheless received criticism for failing to deliver any significant deployment over the forty years since research began. It has been argued that this is primarily due to the technical difficulties of creating reliable, survivable technologies within the marine environment (and integrate them with existing infrastructure) which is simply more challenging than was originally expected (Mueller, 2009, Renewables Advisory Board, 2008, Jeffrey, 2007). Others have contended that due to the absence of actual *materialisation* (i.e. technology deployment and diffusion) the high value placed by developers upon intellectual property (IP) within the industry has created a lack of trust and 'social capital' among stakeholders. This in turn has led to low levels of cooperation, communication and information sharing among and between industry and academia (EPSRC, 2009, POST, 2009, Renewables Advisory Board, 2008). Additionally, it has been claimed that the UK marine energy sector has been driven by only a handful of key stakeholders (Winskel *et al.*, 2006, ICCEPT and E4tech Consulting, 2003).

Much of current innovation theory supports the argument that high levels of knowledge flow within a sector is vital for promoting technological dynamism and innovation as well as pushing forward increases in the legitimacy of high technology sectors (DIUS, 2008, Rogers, 2003, Carlsson *et al.*, 2002, OECD, 1997, Coleman, 1988).

Those relationships that require no interpersonal contact and are based on one-way information flows, (such as reading publications or searching patent databases) can however only provide codified information (OECD, 2005). This is clearly problematic from a policy research perspective since many informal mechanisms of communication, knowledge sharing and learning not only help to strengthen and create confidence in the sector but also produce non-codifiable outputs such as; non-patented innovations, tacit knowledge, collaborative interactions, the establishment of social norms or practices and the creation of social capital (Dosi *et al.*, 2002, Low and Abrahamson, 1997, Coleman, 1988). The presence of knowledge diffusion is difficult to map, though Håkansson suggests that more than two thirds of collaborative relationships are non-formal and thus not picked up by current formal methods of analysis (Hekkert and Negro, 2009, Håkansson, 1990).

This paper explores the activity occurring within the UK's wave energy sector through the framework of Bergek *et al*'s Technological Innovation System (TIS) as well as a through the novel application of network analysis to gain insight into informal linkages and communications occurring throughout the sector (Bergek *et al.*, 2008a, Bergek *et al.*, 2008b). Through the application of network analysis, measures of linkage are established which are used to create a 'map' of *all* interactions that respondents purport to have undertaken including informal connectivity. Metrics of Individual and group centrality are used to quantify key factors within the system such as identifying what Jacobsson *et al.* refer to as *prime movers* influencing the sector's knowledge generation (Jacobsson and Johnson, 2000). Through this technique, as well as established TIS analysis, researchers and public policy makers (as system builders/managers) are enabled to effectively peer inside what Rosenberg describes as the *black box* of innovation, illuminating informal activity and allowing for more informed and therefore effective policy decision making (Rosenberg, 1982).

Research Methodology

The primary research methodology uses status-quo metrics to inform patterns of functional achievement within the framework of the TIS. Secondly, the novel application of network analysis is used to create a 'map' of interactions among stakeholder of the sector. This in turn provides for several empirical metrics (such as centrality or network density) which are then framed themselves under the wider functionality approach of the TIS, described later within this section. These functionality findings were then synthesised into the later stages of a systemic analysis to (as Bergek states) "identify blocking and inducing mechanisms" as well as suggest policy recommendations for system functionality imbalance (Bergek *et al.*, 2008a). Data was collected using two main processes; a comprehensive desktop study and interviews with 43 key stakeholders within the sector identified as outlined below.

Synthesising the TIS with Network Analysis

Most common perceptions of technological innovation systems focus on innovation systems as a network of actors working within a particular technology area, most often (although not always) without a specific geographical constraint (Bergek *et al.*, 2008a, Hekkert *et al.*, 2007, Liu and White, 2001, Jacobsson and Johnson, 2000, Carlsson and Stankiewicz, 1991). The system boundary analysed within this paper was however kept to a national level for several empirical reasons primarily connected to the sector itself, its state of maturity and the physical environment in which it is to operate. Firstly, the UK wave energy sector has a long historical record of wave energy research that has not only been nationally focussed but has also created a national pedigree, culture and established actors network which is still (due to its immaturity) primarily supported through national (and devolved) public bodies. Secondly, many of the current regulatory and legal institutions relevant to the sector are clearly national in nature (e.g. the electricity sector, renewable energy, planning, health and safety, marine operation laws etc.). This second point has been argued by Lundvall who also identified wider societal heritage such as language, culture and education as a validation for national analysis (Lundvall, 1988). Finally, factor conditions affecting the sector which have a national dimension include the resource (i.e. UK coastal waters) and the national grid as well as its institutions of operation (i.e. effectively a large ‘isolated’ grid) support a national focus of analysis.

In addition to the conventional TIS approach, a process of extensive actor identification and interviews was undertaken using a chain referral method of snowballing identification (as outlined by Goodman) conducted until full network saturation (Goodman, 1961). It has been shown that this method has not only been effective at penetrating ‘hidden populations’ but also creates little statistical sampling bias even among non-saturated population studies (Salganik and Heckathorn, 2004). Primary system actors were decided upon as: a) core companies (device developers and key energy utility companies), b) university institutes, c) government departments, d) test centres and the primary marine renewable trade association (RenewableUK). These actor types were chosen on the basis of the triple helix theory of innovation model outlined by Leydesdorff whereby universities and test centres represent the *innovative element*, device developers, trade associations and utility companies represent the *market force* and government agencies represent the *control element* of the helix (Leydesdorff, 2000). The initial system actors were found by assessing the main government marine energy research project; SuperGen2 as well as the European EQUIMAR programme and the European Marine Energy Centre’s (EMEC) Wave Developer list (DECC, 2010b, EquMar, 2010, European Marine Energy Centre, 2009).

All actors had to be based within the UK and currently investigating or working actively within the field of wave energy for interview snowballing to occur. Stakeholders were asked who they were or had been interacting with over the past three years and asked to place this into one of three categories. The first category was, technical knowledge, pertaining to all technical knowledge needed in construction of a wave energy converter including; structural, electrical, mooring and mechanical knowledge. Secondly, market and financial knowledge, including all elements of project costs and revenues, other company related financial opportunities and threats as well as knowledge of wider economic activities affecting the sector. The final category was environmental, planning and regulatory knowledge, both technical environmental knowledge as well as that of ‘institutions’ regulations, and licensing laws under which the wave energy sector operates. They were then asked to value the level of knowledge that they receive from these interaction between 1 and 10 (with 1 being a very minor level of interaction and 10 being a crucial and strong level). Actors who provide a lot of knowledge are said to be *influential* whereas those who acquire lots of knowledge are said to be *prominent* (Hanneman and Riddle, 2005). Actors referenced who were outside of the primary system boundary were added to the network analysis but were not snowballed and therefore took no further part of the study. From a total of 43 interviewed system actors, a further 256 non-system actors were identified as being outside of the system boundary.

Following on from this, a more conventional process of TIS assessment and functionality analysis was undertaken as outlined by Bergek *et al.* (Bergek *et al.*, 2008a, Bergek *et al.*, 2008b). Eight *functionalities* were assessed: materialisation; influence upon the direction of search; legitimisation; knowledge generation; entrepreneurial experimentation; resource mobilisation; market formation; and development of positive externalities. Fifty-one raw data points (e.g. number of full time and part time graduates within different disciplines at each institution) were compiled into thirty three proxy indicators (e.g. FTE graduates). These proxy indicators were in turn compiled to assess the health of the 8 specific *functionalities* (e.g. a low number of FTE graduates would add weight to the argument that there is poorly functioning *knowledge generation* within the sector). Finally, an overview of functionalities within the sector overall enabled an identification of the system health as well as a narrative of sectoral behaviour.

Findings

Networks of activity

The findings for the assessment of network activity occurring within the system overall are broken down into the three different categorical epistemic networks which are summarised and examined individually below.

Rank	Company	Enviro. ΣWIn	Stakeholder Type
1st	Crown Estates	82	Other Company
2nd	Marine Scotland	78	Public Sector
3rd	EMEC	70	Test Centre
4th	Scottish Natural Heritage	53	Public Sector
5th	DECC	49	Public Sector
6th	Aquatera	40	Other Company
7th	Xodus	39	Other Company
8th	Marine Management Organisation	35	Public Sector
9th	Aquamarine Power	31	Device Developer
10th	DEFRA	28	Public Sector
11th	Heriot Watt University ICIT	27	University

Rank	Company	Market ΣWIn	Stakeholder Type
1st	DECC	82	Public Sector
2nd	Carbon Trust	69	Public Sector
3rd	Scottish Enterprise	63	Public Sector
4th	Scottish Government	56	Public Sector
5th	Aquamarine Power	49	Device Developer
6th	Scottish Renewables	48	Industry Assoc.
7th	Renewable UK	44	Industry Assoc.
8th	Highlands and Islands Enterprise	42	Public Sector
9th	Technology Strategy Board	39	Public Sector

Rank	Company	Tech. ΣWIn	Stakeholder Type
1st	University of Edinburgh	101	University
2nd	University of Manchester	71	University
3rd	University of Strathclyde	64	University
4th	narec	57	Test Centre
5th	Queens University Belfast	56	University
6th	Aquamarine Power	55	Device Developer
7th	HMRC University College Cork	55	University
8th	EMEC	50	Test Centre
9th	University of Exeter	49	University
10th	Pelamis Wave Power Ltd	42	Device Developer

Table 1: Top 10 most influential network actors within different knowledge fields of the UK wave energy sector

Within the environmental network three of the five most influential actors (i.e. those that have the highest level of summated weighted 'in ties' as reported by other actors) are public sector bodies (licensing or departmental), while the other two are the UK's longest established and largest marine energy test centre, EMEC (which also has the highest overall summated network influence of 152) and the most environmentally influential actor, the Crown Estate. The two key environmental consultancies Aquatera and Xodus are also shown to be heavily influential, providing a weighted environmental influence of both 40 and 39 respectively towards the system. This level is significantly higher than any university, (the highest being Heriot Watt University ICIT with an influence of 27) and suggests that much of the environmental work being undertaken within the network is now done on a commercial basis rather than as primary research within the remit of universities.

Within the market field, central government departments are most influential (three out of the top five) with DECC coming first, the Carbon Trust second and Aquamarine Power, (the only device developer within the top ten table) fifth. Universities hardly occur on this list at all with Strathclyde being the only influential university market actor within the top twenty at nineteenth (market weighted in score of 19 points) and the rest of the table heavily influenced by the public sector, Scottish stakeholders and key private actors (industry associations, utilities and device developers).

The technical network shows a stark contrast to that of the other two with, universities clearly the most influential institution types (four of the top five being universities, NAREC as the exception) and followed up by the leading device developers Aquamarine Power and Pelamis Wave Power Ltd. The University of Edinburgh dominates followed by the Universities of Manchester and of Strathclyde. The Hydraulics and Maritime Research Centre (HMRC) at the University College Cork provided strong technical influence despite being a 'non-system actor' (outside of the national scope of the system).

These findings are summarised in Table 2 below:

	Summ.	Enviro.	Market	Tech.
Primary Actors	Mixed	Public Sector (Regulators)	Public Sector (Funders)	Universities
Secondary Actors		Environmental Consultancies	Mixed	Device Developers

Table 2: Primary influential actors within different knowledge fields of the UK wave energy sector

Average reported levels of knowledge reception (i.e. whom system actors purported to receive their knowledge from) is shown in Table 3 below.

		Summated Knowledge Average Provision (Influence)					
		Test Centre	Utility Company	University	Public Sector Body	Device Developer	Other Company
Summated Knowledge Average Reception (Prominence)	Test Centre	8	5	46	56.33	19.67	38
	Utility Company	10.4	4.6	17.4	26.8	11.8	8.8
	University	4.71	4.43	55.93	13.07	12.14	21.57
	Public Sector Body	6.4	13.6	5.2	43.8	21.2	9.2
	Device Developer	6.64	3.57	19.21	25.43	0.43	22.36

Table 3: Average system actors levels of knowledge reception for the UK wave energy sector

As can be seen from Table 3, test centres reported to have very high average levels of interaction with public sector bodies, (this is not particularly surprising given the nature of their work). Universities also showed a very high level of interaction among themselves, (this is clearly technical homogeneity as can be seen from Table 1) and (relatively) lower levels of knowledge acquisition from device developers. Device developers themselves rely more on both public sector bodies and ‘other companies’ (supply companies) for most of their knowledge however are still engaged strongly with universities. It can also be seen that device developers hardly interact with each other at all (with an average level of influence below 0.5).

Table 3 quantifies broader claims outlined earlier within this paper related to whether ‘too little’ interaction is occurring within the sector or not and between different stakeholder types relative to the overall milieu of interactions occurring within the sector (e.g. universities and device developers).

Technology Readiness Level (TRL) was used within the system as a proxy indicator of innovative performance for device developers (what could be thought of as an indicator of *entrepreneurial experimentation*). The TRL list was initially conceived by NASA as a method for flight readiness assessment but has since been adopted by others including the US Department of Defence (Assistant Secretary of Defense for Research and Engineering (ASD(R&E)), 2011, Mankin, 1995). The below Table 4 shows the distribution upon the TRL scale for all 14 device developers interviewed.

	Research Stage Description	TRL	#
R&D:	**Applied & Strategic Research**		
	Basic principles observed and reported	1	0
	Technology concept and/or application formulated	2	1
	Analytical and experimental critical function and/or characteristic proof of concept	3	1
	Component and/or partial system validation in a laboratory environment	4	0
	Technology Validation		
	Component and/or partial system validation in a relevant environment	5	3
	System/subsystem model validation in a relevant environment	6	6
Demo:	**System Validation**		
	System prototype demonstration in an operational environment	7	0
	Actual system completed and service qualified through test and demonstration	8	1
	Actual system proven through successful mission operation	9	2

Table 4: Number and technology readiness of UK wave energy device developers

Several UK device developers, (notably Pelamis Wave Power Ltd and Aquamarine Power Ltd, a non and semi-fixed device respectively) have managed to emerge as technology front-runners, (having both now deployed multiple full scale and commercial devices) they are now pioneering deployment and environmental monitoring techniques required for large scale commercialisation. There are no ‘overtopper’ devices currently being commercialised within the UK, however a dominant technology design cannot yet be clearly identified.

There proved to be a strong correlation between technology maturity and the level of influence device developers had upon the system. Correlation is greater still for both the market and environmental networks where mature device developers are intrinsically involved in the formation of standards of best practices and legislation. This correlation of centrality to technology maturity is shown in Table 5 below.

	Tech ΣW-In	Market ΣW-In	Enviro ΣW-In	Sum ΣW-In
Pearson Correlation	0.679	0.745	0.732	0.729
Sig. (1-tailed)	0.004	0.001	0.001	0.002
r^2	0.462	0.555	0.535	0.531

Table 5: Correlation of Different In Centrality Values to Technology Readiness Levels for Device Developers

Government Technology Gating

The influential state of positioning for these most mature device developers was brought about through government policy which has worked as a support *gating* system, providing the (now) most mature device developers with financial support to continue pushing the leading edge of the sector to larger states of deployment while failing to provide finance for other developers to move to full scale commercial deployment. The evidence for this claim can be seen in both historical funding support and the current marine support framework as described below.

The Marine Renewable Deployment Fund (MRDF) was a £42m fund available from 2006 and targeted to support UK wave and tidal demonstration schemes. Funding under the scheme provided for an additional £100/MWh of electricity generation as well as 25% of device capital costs (up to a maximum of £5m) (DTI, 2005b). By 2007, it had been noted that there had been no uptake of the MRDF and the government asked the Renewables Advisory Board to review R&D in the sector (DTI, 2007). Their findings suggested that lack of MRDF access was the result of conditions regarding developer's prior deployment experience (Renewables Advisory Board, 2008). Particularly section 6.1.2.5 stated

> "Prior to entry into the scheme the technology must have been previously demonstrated, operating at full scale in a representative range of realistic sea conditions for at least 3 months continuously (except for planned shutdown) or 6 months cumulatively in any 12- month period, during which designs, performances and costs of your project have been verified."
>
> (DTI, 2005b)

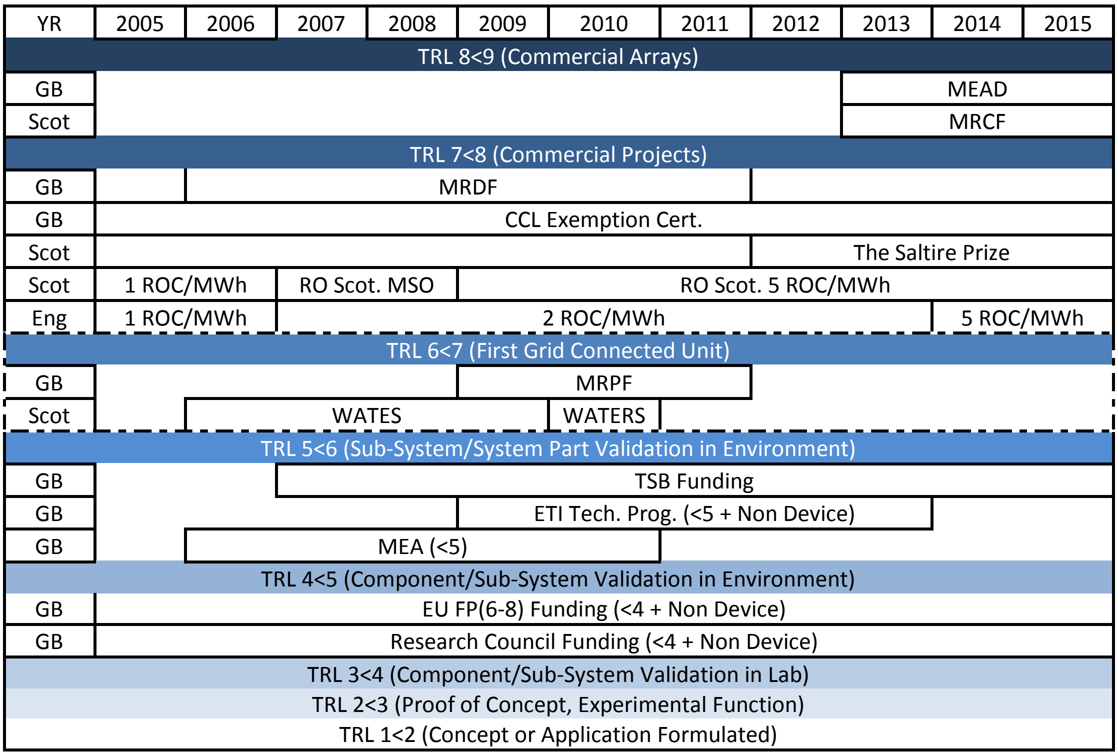
The failure of the MRDF to inject funding into the industry was found to be a failure of communication between the DTI MRDF consultation review panel and the 36 respondents to the MRDF consultation review. During the consultation stage, respondents critiqued the (then) 12 month demonstration requirement that was being proposed by the DTI. In response, the DTI acknowledged this concern and reduced the eligibility criteria of the project to 3 months continuous operation, believing (incorrectly as became apparent) that this would allow the more market ready technologies access to the scheme (DTI, 2005a).

The Carbon Trust (CT) announced in September 2009 that it was launching and managing the (DECC funded) Marine Renewable Proving Fund (MRPF), to "accelerate the most promising marine devices towards the point where they qualify for the Government's Marine Renewable Deployment Fund (MRDF)" (Carbon Trust, 2009b). This £22.5m fund was open to tender for six weeks from announcement, and was secured by what the Carbon Trust believed to be the six most commercially advanced device developers, two of which were wave energy developers (Aquamarine Power Ltd. and Pelamis Wave Power Ltd.)(Carbon Trust, 2010). The MRPF was purely capital support, providing 60% of a developers' first, full-scale commercial project costs (to a maximum of £6m per project) (Carbon Trust, 2009b). In addition to this, the Scottish Government also created both the Wave and Tidal Energy Scheme (WATES) and the Wave and Tidal Energy RD&D Support Programme (WATERS) specifically for full scale device deployment. The primary beneficiaries of these programmes were the two leading technologies (indirectly receiving over £3m each for deployment over both calls)(Scottish Government, 2010). Despite this support, the MRDF still ran for the full 6 years from its initial announcement (until closure in April 2011) without having ever been accessed by a single device developer.

Upon the MRDF's replacement in 2011, the Low Carbon Fund's Marine Energy Array Demonstrator (MEAD) was established. This fund, of £20m has been specifically designed to assist in taking full scale prototypes and creating 'bigger formation in the sea' (i.e. small array demonstrations) (DECC, 2011). The Carbon Trust has also announced the (Scottish Government funded) £15m Marine Renewables Commercialisation Fund (MRCF) for the same purpose of array support (Carbon Trust, 2012). Alongside the announcement of MEAD and MRCF, the recent ROC review has changed banding support provided to wave energy technologies within England from 2 ROC/MWh to 5 ROC/MWh, in line with current Scottish support levels (up to a level of 30MW capacity), reinforcing a shift from 'technology push' support mechanisms to 'market pull' (DECC, 2012b). Finally, although not selected for support, the UK government application to the European Bank NER300 funding included only one wave energy consortium company, POWER (Pentland Orkney Wave Energy Resource) Ltd. This company, a joint consortium of Scottish Power Renewables and E.ON Climate & Renewables planned to deploy 10 Aquamarine Oyster Devices and 24 of PWP's Pelamis devices. Both of whom can be identified from Table 4 as the current UK market leaders (DECC, 2012a, Pelamis Wave Power Ltd, 2011).

The concept of innovative gating contrasts with many current perceptions of the Regulatory State Paradigm and its inability to 'picking-technology winners' within innovation policy. What is occurring within the sector however is not at the alternative side of the 'innovation fault line', (i.e. 'Just Do It' policies) but rather, an un-qualified 'first past the post' selection process which has been in effect since the introduction of the MRDF in 2006 (Mitchell, 2008, Winskel *et al.*, 2006). Despite there being a clear route to commercialisation, there is currently (as there was not before) no equivalent MRPF support for device developers. Although there is an ever-shifting landscape of technology-push grant and mixed grant/revenue support initiatives that are made available from time to time, none currently support devices progression from TRL6, (system/subsystem model or prototype demonstration in a relevant environment) to TRL7 (System prototype demonstration in an operational environment, i.e. first fully commercial grid connected prototype). Access to finance at this stage where the technology has not been fully proven is extremely hard for developers since capital costs for first deployment are estimated to be £10m+ per device (Carbon Trust, 2011, EG&S KTN, 2010).

It can be seen therefore that given this funding landscape and the currently maturity stages of the many UK wave energy device developers, (shown in Table 4 above) a government funding gate of projects has been created as can be seen graphically in Figure 1 below.



<table>
<tr><th>YR</th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th></tr>
<tr><td colspan="12">TRL 8<9 (Commercial Arrays)</td></tr>
<tr><td>GB</td><td colspan="8"></td><td colspan="3">MEAD</td></tr>
<tr><td>Scot</td><td colspan="8"></td><td colspan="3">MRCF</td></tr>
<tr><td colspan="12">TRL 7<8 (Commercial Projects)</td></tr>
<tr><td>GB</td><td></td><td colspan="6">MRDF</td><td colspan="4"></td></tr>
<tr><td>GB</td><td colspan="11">CCL Exemption Cert.</td></tr>
<tr><td>Scot</td><td colspan="7"></td><td colspan="4">The Saltire Prize</td></tr>
<tr><td>Scot</td><td colspan="2">1 ROC/MWh</td><td colspan="2">RO Scot. MSO</td><td colspan="7">RO Scot. 5 ROC/MWh</td></tr>
<tr><td>Eng</td><td colspan="2">1 ROC/MWh</td><td colspan="7">2 ROC/MWh</td><td colspan="2">5 ROC/MWh</td></tr>
<tr><td colspan="12">TRL 6<7 (First Grid Connected Unit)</td></tr>
<tr><td>GB</td><td colspan="4"></td><td colspan="3">MRPF</td><td colspan="4"></td></tr>
<tr><td>Scot</td><td></td><td colspan="4">WATES</td><td>WATERS</td><td colspan="5"></td></tr>
<tr><td colspan="12">TRL 5<6 (Sub-System/System Part Validation in Environment)</td></tr>
<tr><td>GB</td><td colspan="2"></td><td colspan="9">TSB Funding</td></tr>
<tr><td>GB</td><td colspan="4"></td><td colspan="5">ETI Tech. Prog. (<5 + Non Device)</td><td colspan="2"></td></tr>
<tr><td>GB</td><td></td><td colspan="5">MEA (<5)</td><td colspan="5"></td></tr>
<tr><td colspan="12">TRL 4<5 (Component/Sub-System Validation in Environment)</td></tr>
<tr><td>GB</td><td colspan="11">EU FP(6-8) Funding (<4 + Non Device)</td></tr>
<tr><td>GB</td><td colspan="11">Research Council Funding (<4 + Non Device)</td></tr>
<tr><td colspan="12">TRL 3<4 (Component/Sub-System Validation in Lab)</td></tr>
<tr><td colspan="12">TRL 2<3 (Proof of Concept, Experimental Function)</td></tr>
<tr><td colspan="12">TRL 1<2 (Concept or Application Formulated)</td></tr>
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Figure 1: Graphic of funding landscape available for UK wave energy developers with *gating* at TRL6<7

This gating has resulted in the economic equivalent of Merton's 'Matthew Effect' occurring among device developers (Merton, 1968), although Merton applied this term within sociology it is clearly relevant to those device developers within the UK:

> "For to all those who have, more will be given, and they will have an abundance; but from those who have nothing, even what they have will be taken away"
> Matthew 25:29, New Revised Standard Version.

There are two dimensions to this effect within the UK wave energy sector. The first, positive reinforcement for technologies at higher readiness levels who are able to reach further support financing. This also relates to the creation and formation of best practices standard and legislation with which the most mature developers are able to engage in through three ways:

- Practically: Due to their real world work interacting with environmental, planning and regulatory activities.
- Through resources allocation: Since the interaction costs required to engage with stakeholders is proportionally smaller than the operational overheads of the company
- Politically: Since they can afford to play an active role within lobbying bodies (such as RenewableUK) as well as direct advisory bodies such as the Scottish Marine Energy Group (MEG)).

The second dimension is that of system exclusion for smaller device developers. Most perceive themselves to be powerless to influence a number of key areas which impact their development, including the overall *influence upon the direction of search*, the mechanisms by which policies are formed, and argue that they are unable to gain sufficient 'access' to policy makers. This perception is borne out through the network analysis as the collective *influence* (i.e. the summated total values of those who referenced them as a source of information within all knowledge categories) of the lowest twelve interviewed device developers is less than that of the most influential device developer. This can be seen in Figure 2 below.

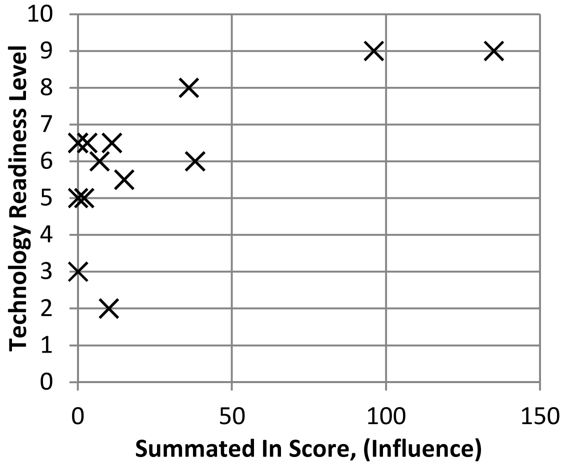

Figure 2: Influence of device developers within the system against technical maturity of device

DECC's Office for Renewable Energy Deployment have argued that their remit is specifically to work with devices ready to deploy and with a focus on 2020 targets, and that they will therefore signpost less mature developers to earlier stage funding bodies (i.e. EPSRC, TSB etc.) (DECC, 2010a).

As technology diffusion starts to occur and the sector naturally matures, technological convergence could be argued as a necessary occurrence (and the increased legitimacy, experience and technology confidence gains that this bestows). It should be expected therefore that some device developers will fail while others succeed. The risks however of excluding less mature developers and concept types from the selection and 'norming' process of system formation currently occurring at this stage of sector maturity may have several negative impacts:

Firstly, the lack of transparency in the financial decision-making process has reduced the overall perceived legitimacy of the system for early stage developers who perceive a lack of 'equality' among developers to be unfairly biased against them. This could lead to a higher number of market exits and thus a reduction in *entrepreneurial experimentation* (i.e. than would be expected with a system perceived to be more transparent and more legitimate).

Secondly, there is a higher likelihood of technology lock-in, the problems of which are that it is not always the technology with the highest development potential that is selected by the market under which it is operating (Arthur, 1989). If a 'dead end' technology is chosen, (i.e. a technology that ultimately cannot compete with international competition or live up to cost reduction expectations in the long term) Sandén *et al.* highlight two ways in which valuable development time may be lost (Sandén and Azar, 2005). Firstly, through alternative, (potentially superior) technologies losing out on cost reducing diffusion or in a worst case, 'organisational forgetting' of codifiable alternatives all together. Secondly, through the self-reinforcing alteration of the overall selection environment and technology search heuristic, since less mature technologies are not engaged with the 'norming' process (e.g. without a leading shoreline-based technology developer, there is less likely to be focus on assessing the suitability for shore-line deployment sites, standards and expectations).

Thirdly, (and following on from the second point) higher market entrance barriers as technology requirements become increasingly higher for new concepts or actors (i.e. technology 'lock-out'). This would again re-enforce perceptions of inequality as well as lock-in characteristics, reducing national firm-firm rivalry and thus having a negative affecting the overall competitive nature of the sector (Porter, 1990).

Finally, there is a higher risk of technology migration, (similar to that which occurred in the early wind industry) as a result of a less disaggregated supply chains for second or third tier products and internal competition which would result in a lower level of internal (national) spend 'sink'.

Policy Support Structure

Although there is a lack of appropriate funding continuity for wave energy developers beyond a certain point, this gating may itself be symptomatic of (or is at least exacerbated by) two other factors: A disaggregated UK funding community and the conceptual 'bundling' of wave and tidal technology together by this funding community. Individually, both of these factors have had adverse effects upon the funding landscape of sector.

There is currently a large and diverse range of funding bodies supporting the UK wave energy sector including: the UK research councils, Technology Strategy Board, Energy Technology Institute, Carbon Trust, Department of Energy and Climate Change, the Scottish and Welsh Governments (and their separate devolved branches such as the Highlands and Islands Agency or Scottish Enterprise), regional administration bodies (councils and formally RDAs, now LEPs), the European Union and several other private bodies such as n-Power Juice and the Crown Estate. Almost all of these bodies hold different funding motivations which including carbon abatement, technology progression, regional economic growth and infrastructural improvement. Findings from the interview process suggested that this has created a disjointed support system whereby both the separate supported actors, (e.g. supporting manufacturers, device developers, universities etc.) and the timeframe of support programmes often do not complement each other. This mosaic of funding and motivations has been identified as detrimental to the growth of the sector and was highlighted by interviewees as problematic (National Audit Office, 2010, Kreab Gavin Anderson, 2010). Examples include the timeframe conditionality of some support spending which has been found to be problematic for long term baseline environmental monitoring requirements. Others have mentioned that applied research funding, although valuable, has left them with 'half complete devices' and no continuation funding meaning that the whole project was a waste of time. Changes in the primary revenue support system, such as the future introduction of a CfD FiT have resulted in higher investor uncertainty. As one prominent device developer CEO mentioned: "The shift from ROCs to FITs has already unsettled potential investors, and what we need now is a stable tariff that will stay in place, and not be tinkered with for a number of years." (McAdams, 2012).

Policy Suggestions

Building on the above issues related to policy support structure, two clear recommendations become apparent; firstly, a clearer separation of wave and tidal support instruments or focus within the policy arena to acknowledge the faster maturation of tidal technology over the past five to ten years. Secondly, the need for a more cohesive and interactive support framework (i.e. between funding bodies) is apparent.

The disaggregation of the support landscape for wave energy is not wholly that of regionalisation verses centralisation as an approach, although coordination between regional and centralised funding and support bodies would clearly be beneficial (if perhaps problematic given the rationale outlined by Smith (Smith, 2007)). This is more clearly relevant for devolved administrative support such as the Scottish or Welsh government and the central UK government agencies where devolved administrations often have both better resources to support local projects as well as a wider remit for planning and other legislative instruments which affect the sector. Since the abolition of the regional development agencies earlier this year, the landscape of regional support (within England at least) has clearly become far more fragmented. The necessity therefore for technology focussed support at this nursing stage of sectoral maturity must address the different stages of technology maturity and therefore focus upon coordination between all public sector bodies who oversee them (i.e. from research councils through to DECC). This finding echoes the recommendations of Foxon et al. who stated “A shared vision for the future of each area of new and renewable energy technology between Government, industry and the research community may be needed to provide an impetus for participants and new entrants to the innovation system” (Foxon *et al.*, 2005). The recent announcement of the Low Carbon Innovation Coordination Group has the goal of assisting with this recognised problem.

To address technology uncertainties and policy decision making concerns, wider accountability and transparency of funding decisions should exist. Although there are different performance and operating characteristics for devices at different stages of technical maturity, public auditing of technology performance characteristics, whether built into grant funding conditionality (as with the MRDF) or publicised through commercial site generation statistics would greatly assist the *legitimacy* of the sector and help to attract outside investment. The key element is that ultimately investors need to know the performance characteristics a particular device (e.g. power matrix, estimated cost, availability etc.) while existing stakeholders need to know that funding decisions are taken objectively and based upon standardised and industry wide measures.

Individually, device developers can currently assist in legitimising their business through three different aspects of certification: These are; certification of company, (through instruments such as ISO9000 certification), technology, (through CE certification, DNV technical certification or the awaited IEC 62600 standards currently in draft) and project, (again, through DNV project certification). Other standards that cover more than one of these fields include standards developed by both the European research project; EQUIMAR and the marine energy test centre EMEC standards.

The aim of many of these standards and certifications is to create a level benchmark for technology appraisal by which potential investors can make comparable assessments and thus provide a lower risk appraisal. This is highlighted in the Green Investment Bank’s cost and benefits section related to marine energy:

> “As has been seen in interviews of the financial community relating to offshore wind, some investors will stay out if they cannot assess the probability

> or severity of downside risk. In other cases, they might demand high returns in order to participate, and this might make the economics of the project unattractive to principal sponsors”
>
> (BIS, 2011)

This paper argues however that all technology developers commercially operating within the UK, and receiving public funding support should be required to benchmark and certify their technology based upon the same standard (e.g. EMEC performance assessment). This would need to be done with an explicit recognition that lower performing devices, at lower levels of technical maturity, are not necessarily subordinate to those of higher performance characteristics which are more mature (or indeed visa-versa). In effect, a hierarchy of technology performance needs to be established and made public to allow investors to assess and appreciate the sectors development.

This could operate similarly to the Test Station for Windmills at Risø Research Centre, Denmark, established in 1978, where availability of public subsidy was only permissible to turbines with approval checks (Karnøe, 1990). Regarding wave energy; technology-push funding should be given to device developers who have undergone benchmarking in which expected device characteristics should be obtained and reported in a standardised and clearly defined procedure/process. For additional market-pull revenue support systems that assist in excess of the RO (such as MRDF or WATES-like schemes): post operational availability, output, overall efficiencies and maintenance publication costs could also be considered as a conditionality for access. This would again allow potential investors such as large utility companies or dedicated renewable project development companies (outside of the device developers themselves setting up project development companies as is occurring currently) prior knowledge from which the risk of investment could be more accurately determined.

Finally, in relation to government technology gating, the creation of an MRPF-like fund for ‘first full scale’ deployment is required. This fund should hold appropriate leverage funding (the MRPF provided 60% of capital up to a maximum of £6m) and should be provided for TRL6 → TRL7 device progression. Access to the future Green Investment Bank (GIB) financing could assist this by allowing private investors to obtain senior debt, while the GIB supplies mezzanine debt (junk debt) due to the higher investment risk they are willing to take (BIS, 2011). This risk reduction measure is important for this particular stage of technology progression where both build/deployment costs (£10m+) and risks are expected to be high. Again, this support should only be available to those developers who have first undergone standards testing as outlined above.

Conclusion

This paper has explored the activities and functionalities currently occurring within the UK wave energy sector using Bergek *et al.’s* Technological Innovation System framework as well as the novel application of social network analysis to identify key relationship patterns within the system.

It has found that certain institutions and stakeholder types play a more influential role within the three different epistemic networks. This is most notable within the dynamic technical knowledge network in which universities and device developers are most active having both high levels of influence and high levels of prominence, with the University of Edinburgh being most central. Within the environmental and planning network, public sector regulators and environmental consultancies are most dominant suggesting that much of the research and consulting work being conducted within this field is now being led by the private sector (specifically environmental consultants Xodus Aurora and Aquatera). Finally, within the market and fiscal network, central government funding agencies are most referenced with DECC being most influential of all. These findings have shown that although the technical problem solving activities within the sector are still very much within the university, R&D remit, other key challenges of environmental planning and assessment are being conducted within the private sector.

Network analysis has shown that as well as high levels of activity within the technical network, there are also relatively higher levels of activity within Scotland and high levels of homogeneity between UK universities. It is suggested that much of this is because technology developers who are at lower stages of technical maturity (specifically below TRL 7 at which they have full scale devices) are isolated from system interactions; (due to lack of finance), sector forming/norming engagement and access to the finance required to deploy full scale devices.

This has occurred as a result of the government 'picking technology winners' through a process of *gating* access to grant finance for device developers over the past six years. Key support instruments for enabling this *gating* have included the (failed) MRDF, the MRPF, the MEAD, the MRCF and the RO. Although it is acknowledged that some technology convergence will likely occur as the industry matures, the lack of transparency behind this decision making process as well as the apparent disjointed nature of the overall funding landscape has left many (less mature) developers perceiving the process to be excluding and unjust. At the same time, those mature UK developers who have been supported to full scale deployment (past TRL 7) are able to engage in early environmental and planning standards formation, as well as moving to access revenue based instruments for multiple array deployments. This has created a *Mathew Effect* among technology developers whereby those that are in the most influential position are supported further while those that are most isolated from the system have larger barriers to overcome.

Several steps are proposed to overcome this perception: Firstly, the de-coupling of innovation programmes for wave and tidal technology together in acknowledgement that wave energy is some years behind tidal technology. Secondly, the creation of a more cohesive funding community for the sector with coupled innovation support instruments as well as a transparent technology selection/requirement process allowing developers to move more fluidly between support instruments. This is hopefully something that could be conducted with the establishment of the Low Carbon Innovation Co-ordination Group. Thirdly, a process to allow the UK test centres to conduct technology benchmarked and certification which all UK developers wishing to access public funds must undergo. Finally, the introduction of an MRPF-like grant support fund for wave device developers at pre-full scale stages of maturity (TRL6) prioritised to those with higher technology performance assessments (as identified by NAREC/EMEC).

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