Quantifying Methods for an Innovation Systems Analysis of the UK Wave Energy Sector

Submitted by Angus Robert Vantoch-Wood, to the University of Exeter

as a thesis for the degree of

Doctor of Philosophy in Renewable Energy

In October 2012

Volume 1 of 2

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

(Signature) ……………………………………………………………………………

Abstract

Current proxy indicators of innovation although insightful, tend to provide more relevance in both larger scale markets, (such as in the pharmaceuticals or electronics industry) and for codifiable innovative activity, (such as patents and bibliometrics). These measures could be capitalised on further if a more robust measure of functionality performance that included informal innovative activity could be gained to help assess the overall performance of the system under inspection.

This work uses the emerging UK wave energy sector as a primary case study to explore early stage innovation systems through the novel application of network analysis as well as existing innovation systems theory. It was hoped that a clearer understanding of which metrics were related to which system *functionality* and how representative they were would help to create more robust and transferable measures of emergent system functionality. The question as to whether this increased confidence and insight into system operation could allow for benchmarking comparisons between spatially or socially different emerging innovative networks, such as different countries or stakeholder types was then addressed, as well as wether this could provide a higher level of efficacy to applied policy support?

A further goal of this work was to assess the current wave energy sector through these methodologies and provide insightful feedback into activity, potential opportunities and threats present within the system.

The main methodological findings show that the novel application of Social Network Analysis provided a strongly correlated and insightful metric of innovative activity however (as with established metrics), there were clearl limitations on applicability and that a 'one size fits all' application of methods is not available for any innovation assessment tools. Additionally, many existing metrics used within analysis are often un-clearly defined or presented leaving largely presumptuous levels of interpretation within the final analysis.

Sectoral findings showed a range of narratives regarding the sector. Clear prominence of Scotland and higher levels of all system functionality within the country make it a strong performer within the system. Likewise, a lack of coherent and 'first-past-the-post' funding

policy has produced a ‘gating’ of technology support that in turn has disillusioned many early device developers while pulling out a fortunate few. This ‘Mathew Effect’ within the system may (among other things) leave the sector open to system shocks from outside competition and reduce the level of market entrance due to a perception of unfair or secretive support provision.

Master Table of Contents

Volume 1

Volume 2

Master Table of Figures

Master Table of Tables

Master Table of Equations

Chapter 2

Personal Thanks:

The author of this thesis would like to purvey his sincere personal thanks to his supervisors, Dr Peter Connor and Prof. Catherine Mitchell for all of the guidance and support over the four years it has taken to complete this work. He would also like to thank the many interviewee respondents who have assisted with his work and provided the valuable insights that have fed into it. Finally, he would like to pay special thanks to his wife; Nicola Vantoch-Wood, for the great deal of personal support and understanding that she has provided over the years.

List of Abbreviations

Acronym:	Description
£MW/h	Pounds per Mega Watt per Hour
BERR	(Department for) Business Enterprise and Regulatory Reform (Defunct UK Department 2007-2009)
BETTA	British Electricity and Trading Agreements
BIS	(Department for) Business Innovation and Skills (UK Department 2009-)
CCL	Climate Change Levy
CfD	Contract for Difference
CPA	Coasatal Protection Act 1949
CT	Carbon Trust (UK Company Limited by Guarantee 2001-)
DECC	Department for Energy and Climate Change (UK Department 2008-)
DEn	Department of Energy (Defunct UK Department 1974-1992)
DIUS	Department for Innovation, Universities and Skills (Defunct UK Department 2007-2009)
DTi	Department for Trade and Industry (Defunct UK Department 1970-2007)
EA	Environment Agency (UK Non-Departmental Public Body 1996-)
EA	Electricity Act 1989
EDF	Électricité de France (French Utility Company 1946-)
EG&S KTN	Energy Generation and Supply Knowledge Transfer Network (UK, TSB Led Project 2009-)

EMEC	European Marine Energy Centre (UK Marine Energy Test Centre 2001-)
EPRI	Electrical Power Research Institute (US Non-Profit Research Institute)
EPS	European Protected Species
EPSRC	Engineering and Physical Science Research Council (UK Research Council 1994-)
EquiMar	Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact (EU Marine Research Project)
ERPem	Edinburgh Research Partnership in Engineering and Mathematics (Edinburgh Research Consortium)
ESRC	Economic and Social Research Council (UK Research Council 1965-)
ETI	Energy Technology Institute (UK Private-Public (50/50) Partnership Company 2008-)
EU	European Union (European Political Union)
EU-OEA	European Union Ocean Energy Association (EU Marine Trade Association)
FEPA	Food and Environmental Protection Act 1989
FiT	Feed in Tarrif
FREDS	Forum for Renewable Energy Development in Scotland
FTE	Full Time Equivalent
GERD	Gross Domestic Expenditure on R&D
GHG	Greenhouse Gases
GIB	Green Investment Bank
GoO	Guarantee of Origin

GW	Giga Watt
GWh	Gigawatt Hour
IEA	International Energy Agency (OECD Agency 1974-)
IS	Innovation System
kW	Kilowatt
kWh	Kilowatt Hour
LEC	Levy Exemption Certificate
MARINA Platform	Marine Renewable Integrated Application Platform (EU Marine Research Project)
MCAA	Marine and Coastal Access Act 2009
MEAP	Marine Energy Action Plan
MEG	Marine Energy Group (Scottish Marine Stakeholder Group 2003-)
MMO	Marine Management Organisation (UK Non-Departmental Public Body 2010-)
MNC	Multi-National Company (or Conglomerate)
MPS	Marine Policy Statement
MRCF	Marine Renewables Commercialisation Fund
MRDF	Marine Renewable Deployment Fund
MRIA	Marine Renewables Industry Association (Ireland)
MRPF	Marine Renewable Proving Fund
MW	Mega Watt
MWh	Megawatt Hour

NAREC	New and Renewable Energy Centre
nm	Nautical Miles
NDPB	Non-Departmental Public Body
NFFO	Non-Fossil Fuel Obligation
NFPA	Non-Fossil Purchasing Agency Limited (UK Agent for Electricity Obligation 1990-)
NIS	National Innovation System
OSPAR	The Convention on the Protection of the Marine Environment of the North Sea
OWC	Oscillating Water Columns
PerAWaT	Performance Assessment of Wave and Tidal Array Systems (ETI Led Marine Research Project)
pkWh	Pence per Kilowatt Hour
PoCP	Proof of Concept Programme
PRIMaRE	Peninsular Research Institute for Marine Renewable Energy (SWRDA Led Marine Research Project)
QUANGO	Quasi-Autonomous Non-Government Organisations, (now refered to as NDPB)
RD&D	Research, Development and Demonstration
REGOs	Renewable Energy Guarantees of Origin
RET	Renewable Energy Technology
RIS	Regional Innovation System
RO	Renewable Obligation

ROC	Renewable Obligation Certificate
SEA	Strategic Environmental Assessment
SME	Small to Medium Enterprises
SNA	Social Network Analysis
SNH	Scottish Natural Heritage (Scottish Non-Departmental Public Body 1991-)
SOHO	Small Office/Home office Enterprises
SSE	Scottish and Southern Energy (UK Utility Company 1998-)
STEM	Science, Technology, Engineering and Mathematics
SUPERGEN	Sustainable Power Generation and Supply (EPSRC Energy Research Project)
SWRDA	South West Regional Development Agency (UK Regional Development Agency 1999-2012)
TIS	Technological Innovation System
TSB	Technology Strategy Board (BIS Accountable Public Sector Body 2007-)
UKCES	United Kingdom Commission for Employment and Skills (UK Non-Departmental Public Body 2008-)
UKERC	United Kingdom Energy Research Centre (UK Research Council Led Project 2004-)
UKTI	United Kingdom Trade and Investment (UK Department 2003 -)
UNCLOS	United Nations Convention on the Law of the Sea 1982
VC	Venture Capital(ist)
WAG	Welsh Assembly Government (Welsh Devolved Government)
WATERS	Wave And Tidal Energy: Research, Development and Demonstration

	Support
WATES	Wave and Tidal Energy Scheme

1. Introduction

Table of Figures:

1.1 Chapter Introduction

This chapter, provides an introduction and justification for both the primary focus of research within this work, (the UK wave energy sector) as well as the primary analytical approach and field of primary contribution within this work , (systems of innovation and social network analysis).

Although it does not include the research questions or methodology in any respect, it should provide the reader with a clear justification for the research.

1.2 Why Wave Energy?

It is now widely accepted among both the scientific and political community that the world is undergoing environmental change as a result of the increased levels of greenhouse gases- specifically carbon emissions - into the atmosphere.

Although the amount of both human influence and environmental effect of this change are still somewhat less defined, our best estimates indicate that a UK decrease of overall greenhouse gas (GHG) emissions by 80% on 1990 levels is required if we are to play our part in avoidance of what are considered to be severe and irreparable environmental changes resulting from a +2 degrees centigrade level of temperature increase worldwide (IPCC, 2007a).

The decarbonising of our economy presents a multitude of challenges (and indeed opportunities) the likes of which our society has not seen since the Second World War, with our transport, heating and electricity demand each contributing to around one third of our total energy consumption (DECC, 2010a).

Currently, one of the most promising methods for decarbonisation lies in the use of renewable energy technologies. Renewable energy can provide heating (through biomass or solar thermal technologies), transport (through bio-fuels etc) and electricity (through a wide range of renewable energy technologies (RET)).

Concerns however over the land space, sustainability and fuel security of biomass technologies have led some to argue that electrification of both the heating and transport sector is the best all round method to decarbonise our economy at large.

This in turn would place a massive burden on our electricity sector at a time when carbon austerity and nuclear safety (following the recent Fukushima incident) concerns are high, massive investment in transmission infrastructure is required and an overall uncertainty regarding the capability of renewable electricity (specifically wind powers') to provide generation upon demand is felt. There is clear need to increase our options

Within the range of these options come nuclear fusion technology, carbon capture and sequestration (CCS) and alternative renewable energy technologies. Each option has its own merits and pitfalls, as well as the related challenges presented by massive technological, economic and associated risks.

This thesis looks at only one slice of one of these options in greater detail. It makes no claims for a 'silver bullet' solution to the wider problems mentioned above. It hopes however to provide supporting insight into a field of research in which the author believes there is a great un-tapped potential to help contribute to our need for both the decarbonisation of our economy (while providing increased economic prosperity) and increased security and reliability of our energy supply in a way that provides long term sustainability at a more acceptable environmental cost.

All of these benefits could potentially be provided through the successful emergence of a UK based and supported marine renewable energy sector. Although the successful commercialisation of both wave and tidal technologies would provide a valuable contribution towards the above goals, wave energy is seen as having a far higher global potential to contribute to energy generation. This is due to the larger practical, technical (and hopefully in the future) economic resource availability that it provides.

The benefits of commercialising wave energy generation have been highlighted by many within the political advisory field, energy sector and wider renewable energy sector itself.

These benefits include the following:

- The waters around the UK are considered to be among the best in the world as a source of both wave and tidal marine renewable energy and could provide 15-20% of our electricity supply needs saving tens of $MtCO_2$ (Renewables Advisory Board, 2008)

- Wave energy available within the UK, although more erratic in its generation characteristics then combustible sources, produces, on average five times as much energy during peak demand than it does during periods of low demand. Lower levels of hour to hour variability than tidal energy, (which is however more predictable) and fairly accurate predictability up to several days in advance, ultimately meaning much easier integration and fewer demands on the grid (POST, 2009, The Science and Technology Committee, 2001, Carbon Trust and Environmental Change Institute, 2005).
- Wave (and tidal) technology can (and almost has to be) incrementally deployed. This means that (unlike nuclear or other centralised generation) environmental monitoring and discovery of affects can be done concurrently with deployment as capacity ramps up.
- World export potentials (for wave and tidal technology combined) are estimated to be in the region of £60b <£190b per annum (Carbon Trust, 2006).
- It is estimated that as many as 16000 people could be employed within the wave energy sector by the 2040s (Carbon Trust, 2009a).
- There are low levels of availability variation within different device types with wave energy availability being the dominant factor meaning that devices are substitutable on larger arrays and therefore technology ‘lock-in’ is not a impending problem (Carbon Trust and Environmental Change Institute, 2005).
- 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 leading research institutes in the sector (Entec UK Ltd, 2009, Winskel *et al.*, 2006, Douglas-Westwood, 2008).
- Diversifying the overall energy mix of renewable energy technologies reduces the risks faced if only one technology encounters large problems in performance, reliability or supply chain requirements. This diversification could also lead to a potential reduction in extra renewable capacity requirement that would save around £900m per year in costs (DECC, 2010b).

1.2.1 Problems with the Wave Energy Sector

Despite this great potential, one of the underlying difficulties facing the wave sector is that the UK wave energy industry is clearly still very much in its infancy. It could indeed reasonably be argued that it is hardly an industry but rather, a 'supported niche' created purely by direct government leverage funding, since (given the current generation costs of wave energy technology), there is little incentive to commercially develop the technology without subsidy and very little influence in the way of 'market pull' (i.e. generation revenue) incentive.

The nature of the technology itself, (what Law and Bijker (1997) refer to as the 'script' of the technology) ensures that innovation has to occur from a top-down perspective rather than from 'grass-roots' (Law and Bijker, 1997). Heavy planning, environmental and technical requirements for offshore cabling, foundation building and connecting to the grid imply that "starting small and getting bigger" (as was the case within the Danish wind industry for example) can only be achieved within a managed technology nurturing process, through scaled test centres where the required infrastructural equipment and skills can be communalised.

Indeed, only a handful of the UK's 20 or so current wave device developers have even built full scale prototypes let alone commercially deployed devices. As a result of this, many companies have little in the way of stable and regular revenue streams, there are high level of risk and uncertainty within the sector, and many device developers appear to be 'stuck' at the R&D stage of development (Winskel *et al.*, 2006, ICCEPT and E4tech Consulting, 2003).

There are many current problems within the offshore marine renewable sector that have been identified by previous studies such as:

- The technical difficulties of creating reliable technologies that are can operate and survive within the marine environment reliably are simply much more challenging than originally expected (Renewables Advisory Board, 2008).
- A lack of physical and validated knowledge (based on actual practical experience) of the wave resource, electricity networks and economic models (Jeffrey, 2007).
- The connection between the university base and industry could be stronger (EPSRC, 2009).
- There are challenges identified relating very much to the technology, however industrial infrastructure is also a major challenge facing the sector (Mueller, 2009).

- Marine energy innovation is being driven by only a few small developer firms, with only limited links between developers, component suppliers and universities. (Winskel *et al.*, 2006, ICCEPT and E4tech Consulting, 2003)
- Co-operation between different industry players could be improved and best use is currently not being made from the results of current academic research. (Renewables Advisory Board, 2008)
- Developers' concerns about compromising high valued intellectual property (IP), restricts information sharing and collaboration (POST, 2009). Funders are faced with difficulties in establishing the characteristics of devices and allocating funding
- There is an outstanding need for increased financial support, grid access and planning permissions (British Wind Energy Agency, 2006).
- More generally in regards to UK renewable energy support, coordination of direct support for renewable energy has historically been limited, with each delivery body developing its own approach in accordance with its own objectives.(National Audit Office, 2010)

These problems are clearly identifiable barriers and due to the diverse nature of causality behind them, (i.e. natural environment, technological, socio-political, economic etc…) need to be addressed on either a problem-by-problem basis or within clusters related to their origin to ensure that the sector continues to mature.

Some problems result from the politically unstable systemic establishment of the wave energy sector itself. For example, if there is an overall lack of confidence or 'legitimisation' in the sector and its technology, then the perceived risk of entering the sector is high and, gaining access to finance will become more difficult. Likewise, this lack of legitimisation will affect both the perceived importance of establishing more defined and favourable planning guidelines/regulations as well as the number of new entrants coming into the sector.

A great deal of current economic theory suggests that high levels of knowledge flow and diffusion within a sector are vital for keeping technological dynamism and innovation as well as pushing forward increases in the legitimisation of the sector (OECD, 1997, Carlsson *et al.*, 2002, DIUS, 2008).

There are clearly complex feedback loops within an analysis that looks at broader system categories such as 'knowledge diffusion', 'legitimation' and 'materialisation', (which provides both ‘learning by using ’ knowledge generation (Rosenberg, 1982) and legitimation. To resolve many of the larger systemic barriers to the marine renewable energy sector however, a ‘whole system’ view of the technology, supporting ‘factor conditions’ (such as knowledge, capital, human and physical resource (Porter, 1990)), support policy, and indeed social landscape affecting the wave energy sector itself needs to be analysed, and to achieve this an innovation systems perspective is required.

Much innovation theory within the renewable energy technology context has looked at successful examples of support systems, most notably studies of Denmark’s wind industry success, (Karnøe, 1990, Jørgensen, 1995, Johnson and Jacobsson, 2002), and has thought to transpose policies over to other systems for potentially prescriptive insights, (there is however some examples of systemic failure available (Bergek, 2010)).

Although there is value in understanding these systems, this method holds clear limitations since all systems differ in technology, locality and both local and global societal values. Whilst some comparisons can be made between the Danish wind industry and the UK's emergent marine energy sector, these should not be considered absolute indicators as to the nature of appropriate policies to support the UK marine energy sector without first gaining a broader understanding of the marine energy system first.

Issues raised by these comparisons include:-

- The clear technical differentiations: The nature of wave technology and interaction with the physical environment, (i.e. the waves) creates design restrictions of scale that are very dissimilar to wind. Besides the physical characteristics of wave sizes, frequency etc, the interactive relationships in which the power output is proportional to the swept area of a wind turbine, (rather than the blade length) needs to be considered. The result of this is an initial requirement for both large-scale and technically complex wave devices, which creates natural barriers to entry beyond a certain, non-grid ready (and thus non commercially feasible) scale testing.
- The isolated nature of offshore wave resources means that the infrastructural requirements for both deployment and product development are far higher for wave technology than for the early pioneers of wind energy generation technology (since wave tanks etc... are required). Thus, a scaling up of wave technology cannot naturally occur from a lay ‘bottom-up’ approach as was achieved in the Danish wind sector

(Karnøe, 1990). This in turn has implications for support policies and the wider innovation support framework.

- Social acceptance, the Danish wind industry (which grew to provide the Danish concept technology that dominates the current wind energy sector) had grassroots support as the then sole renewable energy technology presenting a favourable alternative to an unpopular nuclear choice. The wave sector can be argued as 'competing' with other renewable energy sources for fiscal support and efficacy of both cost and C02 savings, including those that are more technology or commercially mature. This affects not only the skills resource available but also the social incentive for wave energy. There is therefore a less clear distinction as to whether wave energy is answering an economic need and/or a social challenge, bringing up questions of 'value' and 'trust' within the sphere of social consciousness within the sector.

1.3 An Introduction to Innovation

The field of Technological Innovation Systems analysis has proved a valuable theoretical framework in helping to understand the means by which technological advancement occurs within different industrial fields. Its strengths lie in its provision of a conceptual and applicable methodology with which to assess what is a stochastic process among heterogeneous stakeholders (who often hold differing motivations).

Within all innovation literature,- knowledge creation, diffusion and the concept of 'interactive learning' between agents are seen as core processes in enabling innovative activity. It is therefore vital that policy makers can measure and assess these levels in order that policies can be put in place to ensure that the system fulfils its maximum potential.

Current indicators focus upon formal, codified forms of knowledge such as; patent records, publication analysis, firm/university reports and R&D expenditure. Although these indicators provide valuable insights, they ignore many 'informal' innovative outputs. The actual process of systemic knowledge generation and diffusion, though best assessed through formal collaborations is often simply left as part of the 'black-box' of innovation, leaving analysts to make tacit intuitive assumptions about whether 'enough' interaction is occurring within the system (see Figure 1 below).

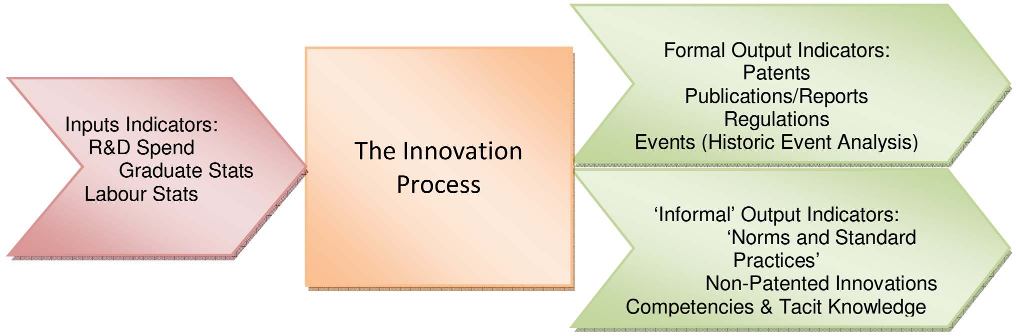


Figure 1: Innovation Indicator Flow

This has resulted in growing awareness of the limitations and drawbacks which current indicators hold in allowing researchers and policy makers to understand some of the outputs of innovation activity which we know to occur.

As well as looking at the validity of existing indicators of innovation within the wave energy sector, the focus of this thesis explores the feasibility of directly quantifying the flows knowledge interaction between system actors at the meso-scale of industry activity using the emerging field of social network analysis (SNA). By directly asking stakeholders to quantify their perceived levels of interaction with other actors, a clear network map of system interactions (which are a proxy indicator for knowledge flows) can be constructed to form an *epistemic network* and SNA analysis tools can be applied. This methodology is applied to the emerging UK Wave Energy industry in the hope that it can provide both practicable application and useful insight into the industry's emergence.

Additionally, SNA has been used to provide more structural insight into some of the quantitative data that is available; specifically it is applied to patents where it is used to evaluate historic influences on current technology state-of-the-art.

1.3.1 Problems with Innovation Systems Analysis

The field of innovation systems analysis has allowed policy makers to develop approaches for enhancing our understanding of innovation itself (OECD, 1997) such as the innovation system which represents the UK wave energy sector. Although methods of analysis have advanced greatly since their early conception (as detailed in the literature review chapter), application to systems which are at a stage of maturity as early as the wave energy sector are still far from robust as high levels of systemic uncertainty and exogenous factors have a larger influence upon the system then some current indicators.

Relying on existing indicators such as patents, citations and levels of deployment can produce insightful results but fall short on giving the assessor a strong understanding of the sector for several reasons outlined below:

- Patents often give a misleading measure of the sectors innovativeness for several reasons:
    - Many innovations are not patented, and some are covered by multiple patents; many patents have no technological or economic value, and others have very high value (OECD, 2005).
    - Searching patent databases for patents directly related to the wave energy sector is complicated by the heterogeneity of not only product designs but also sheer complexity of devices that often involve a large array of technology types, (i.e. power, civil, structural and mechanical engineering, electronics, hydraulics and more.) This makes identification of relevant patents a complex process.
    - Although patents are an important element for industrial development, many firms within the early emergence of a sector may purposefully not patent their technologies since the advantages of exclusivity can in some instances be gained through other measures (such as both lead times and simple device construction secrecy). Additionally, publishing through patent application allows competitors to not only evaluate their progress and design but can potentially remove lead-time advantage through informing rival companies of technical search heuristics.
    - There is a recognised 'patent-paradox' which has occurred over the past two decades which unilaterally show that although firms do not consider patents

efficient at either excluding patent technological infringement or protecting innovation, more patents are nonetheless being issued annually (Kortum and Lerner, 1999, Julien, 2009). This finding suggests that patents on their own do not provide a definitive insight into either knowledge generation or innovative activity within a sector.

  - Nelson states: 'One can see the task of institutional design as somehow to get the best of both worlds. Establish and preserve property rights, at least to some degree, where profit incentives are effective in stimulating action, and where the costs of keeping knowledge private are not high. Share the knowledge where it is of high cost not to do so, and the costs in terms of diminishing returns are too small' (Nelson, 1988). This implies that when there is a high enough public need to unlock knowledge (held by patents for example), then good 'institutional design' must somehow create a platform to share this knowledge or else there is a detriment to the sector. (An example of this could be the validation of the numerical modelling within the wave energy sector that was highlighted in section 1.2.1 above, (Jeffrey, 2007).
  - The 'tragedy of the anti-commons' theory (Heller, 1998a, Heller, 1998b, Dosi *et al.*, 2006a) suggests that over patenting can in fact lead to a lack of efficiency within the market as fragmented intellectual property rights (IPR) excludes all users from making progress within the knowledge base of the sector. (This is however unlikely to be the case within the wave energy sector specifically however it shows that patent numbers can distort levels of innovation and fields such as the oil and gas sector which are technologically similar to the wave energy sector *may* be more affected leading to 'negative externality spillovers').

- With regard to linkages (relationships)- those that require no interpersonal contact and are based on one way information flows, such as reading publications or searching patent databases, can only provide codified information (OECD, 2005). Many informal mechanisms of knowledge generation however help to strengthen and create confidence in the sector but lead to non-codifiable outputs (such as non-patented innovations, tacit knowledge, collaborative interactions, establishment of social 'noms' or practices and the creation of social capital through support networks/contacts) as stated:

    - Theories of successful emerging industry suggest that informal mechanisms are used to increase legitimacy, confidence and knowledge within an emerging industry (Low and Abrahamson, 1997).
    - On average more than two thirds of all collaborative relationships are non-formalised and are thus not picked up by formal methods of analysis (Håkansson, 1990).
    - R&D statistics are really a measure of the professionalization of R&D activity, *(or scientification)* and no not include 'informal' R&D that is usually carried out in the 'lower' level technology fields, (i.e. measuring large pharmaceutical company research as opposed to individuals or SOHOs inventing bespoke solutions) (Freeman and Soete, 2007).
- Qualitative forms of understanding of a sector may be the most informative, especially within the early stages of a niche innovation system where a larger proportion of the sector can be understood by a single individual. The inherently tacit nature of a 'narrative' understanding of a sector and the knowledge flows within it, means that replicability of the study (and thus long term reliability in findings), are hard to achieve without an embedded observer. As Winskel states: "Informal factors, such as common backgrounds and understanding between developers, researchers, and suppliers, are largely tacit and culturally embedded, and therefore not easy to make explicit in policy reviews." (Winskel *et al.*, 2006).
- As Hekkert and Negro state: "The role of knowledge diffusion is difficult to map. We have been able to measure the events where knowledge diffusion is likely to take place, such as workshops, conferences and technology platforms. However, the actual knowledge diffusion process could not be measured in this way." "Much knowledge diffusion takes place in dyadic relationships that are not reported in the literature." (Hekkert and Negro, 2009)
- Foxon states: "Systems of innovation approaches have traditionally started from empirical case studies that examine factors. Though these serve to illustrate the complexity of interactions, they have been criticized for failing to provide clear guidance to entrepreneurs and policy makers." (Foxon *et al.*, 2008)
- Much innovation systems literature is heavily theoretical in its background and although some authors suggest proxy indicators for assessing the development of functionalities, (such as 'assessing the emergence of pooled markets for positive externalities' or 'attitudes to the sector for legitimacy'), the process of operationalising

and acquirement of this knowledge is largely left un-explored. “To be really helpful in that regard, system approaches are in need of substantial elaboration and refinement” (Fagerberg *et al.*, 2005).

- Finally, as stated earlier, within a weak system paradox, the individual actions of strong actors can have an effect on the system as a whole.

Although the nature of innovation is implicitly stochastic, the current lack of robustness in the measuring indicators within early stage innovation, as well as the complex and multifaceted nature of the wave energy sector itself (and indeed any emerging innovation system) can lead to problems of confidence for policy makers when deciding which policy tools to deploy and how best to support the sector.

This in turn can lead to long term incoherent and inconsistent signals of support to industry that will thus diminish many of the functionalities of the system itself (such as legitimation, market formation, entrepreneurial experimentation) and bestow the subsequent negative connotations that a lack of these functions implies.

Since most central and regional government policies regarding the promotion of renewable technology aim to both increase deployment (thus achieving carbon emissions reduction targets) and create a related industrial base and workforce developing a more comprehensive understanding of these theories and their application will help contribute to greater renewable system understanding. This in turn will help the development of appropriate policy support mechanisms, thus meeting the policy objectives themselves.

1.4 An Introduction to Social Network Analysis

Given the above issues with current innovation indicators, one of the primary goals of this thesis is to try and establish a method of codification for these informal interactions and communications within the system through the application of social network analysis.

Social network analysis (SNA) is a relatively new field of social science that amalgamates elements of graph theory with different components of sociology. The key sociological aspect of SNA however is its focus on relationships between different social entities (Wasserman *et al.*, 2005) or ‘nodes’ as they are often called in network analysis. These relationships are often between nodes that represent individuals. Network analysis can however be applied to the relationships between entirely inanimate nodes such as network cables between computers or interactions between organisations (as is the case within this thesis). Although some of the theories and metrics of established SNA as applied to individuals can be directly transposed to inanimate forms of nodes (such as network density and centrality), other theories around networks (such as relational transitivity for example) may not.

Researchers of innovation policy largely accept that an understanding of the linkages and knowledge flows within innovation are of direct relevance for innovation policy itself (OECD, 2005, Hansen, 1999) and that indeed, as Powell et al states: "The locus of innovation can be found in networks of learning rather than in individual firms. Therefore the structural, relational and individual stakeholder information that could be gained from application of network analysis to networks of innovation may provide valuable insight for policy makers (as system managers/promoters) and entrepreneurs alike."(Powell et al., 1996)

Using SNA to analyse an innovation system will involve clearly defining the stakeholders to be assessed within the system and conducting a complete (saturated) analysis so that a full network map of all actors is produced. One also needs to also consider the various levels of interaction resolution that can be applied, (i.e. binary or numerical strength relations, directed or mutual relationships etc.), the different methods for data gathering (direct interviewing, informant system, desk based search of relationships etc.) and particularly the different system boundaries that can be used, (i.e. including/excluding technology developers, government bodies, universities etc.) Each of these options holds differing pros and cons and shall need evaluation prior to commencement. However a balance between the resources committed to the study, the size of the system and the level of detail required (such that 'systemic externalities' are kept to a minimum to allow a realistically achievable study) shall be the overarching goal.

1.5 Brief Overview of Research

Given both the potential of network analysis to assist in our understanding in the processes of innovation (especially within emerging industries) as well as our desire to accelerate and assist in the commercialisation of the UK wave energy sector, the goals and original contribution of this research is threefold:

1. To create a better understanding of emerging innovation systems through the application of existing measures of innovation detailed by existing academics and policy documents.
2. To attempt to enhance and strengthen these metrics further through the creation and validation of a suite of measures/metrics of system functionality explored through the application (and a theoretical understanding of), Social Network Analysis.
3. To come to a deeper understanding of the emerging UK wave energy sector which could in turn allow for the generation of normative policy suggestions for system improvement and capacity building.

Primarily, the application of SNA shall be used to create a multidimensional epistemic network of stakeholder interactions occurring within the emerging wave energy sector, from which more standard tools of network analysis can be applied and benchmarked against existing metrics.

Ultimately it is hoped that these extra measures will provide for stronger confidence and insight into innovation activity within a wider range of emerging innovation systems (especially 'informal' innovation activity) which will in turn provide for an increased accuracy of monitoring and resolution of system functionality performance. A greater and more accurate understanding of which policy instruments have what affect on which functionality, (in the context of a particular social milieu) will not only increase overall policy efficacy but also allow for greater understanding of the policies themselves.

The question then emerges as to whether this increased confidence and insight into system operation can allow for benchmarking comparisons between spatially or socially different emerging systems, thus helping to provide a higher level of efficacy to applied policy support? Efficacy in this context can be defined as the effectiveness of the public policy goals in achieving its targets, be they higher levels of technology deployment, increased regional industrial development, increased employment or faster levels of technology cost reduction per unit of cost or time.

Clearly there will be limitations and caveats on this approach to systemic analysis. In the early stages of a systems evolution, (exogenous) elements play a dominant role (Bergek *et al.*, 2008a) until the system evolves and expands out of an incubated niche status and has developed strong enough internal functional dynamism to withstand outside influences. Although the system itself initially forms from through the combinational diversification of existing systems (e.g. actors diversifying from R&D activity within the hydrocarbons sector), there is a clearly distinct impetus for those actors entering the newly emergent system than that of their progenitor sector. This activity may itself be a structurally motivated from within the original system (e.g. a desire to mitigate against risks from emerging technologies for those within the energy sector), non-structurally (agency) based (e.g. a desire to mitigate the effects of climate change), or in some part a combination of both. *How* the system, (through the empowerment of its constituent actors) brings many of these external factors under its control and within the systemic sphere of influence (through increased policy support, key stakeholder 'buy-in' etc.) is part of the formation process and by understanding this, we can ensure that external factors are recognised as 'random' in respect to the system (and not mistakenly viewed as endogenous to system formation).

The following chapter (the Literature Review) will introduce many of the mathematical and conceptual detailing regarding both; innovation systems theory, social network analysis and many of the other supporting concepts from which, the body of knowledge within this thesis draws upon.

2. Literature Review

Table of Figures:

Table of Tables:

Table of Equations:

2.1 Chapter Introduction

The mainstay of this thesis is based on the theories of evolutionary economics, innovation theory and technological transition combined with a strong element of graph theory, (social network analysis), energy policy, (related to the GB marine energy sector) and to some degree upon a practical technological understanding of marine renewable energy (specifically, wave energy converters).

The following chapter therefore outlines the background theory related to these topics in a more broad and generalised way so that application of key concepts can be derived and referred to within later sections of the work. This review of current theory is ordered in a thematic way such that it provides both a more fluid flow to the reader but also can be used as a reference on specific topics if needs be. Energy policy, and in particular, the current status-quo on marine renewable energy policy, are covered more comprehensively within Chapter 3, the Background Review of the Sector.

2.2 The Reasons for an Evolutionary Economic Approach

Economics is the study of the way in which, as a society, we govern and manage the distribution of wealth, products and services. Many people have slightly varying definitions of what economic theory entails but put simply, it is the study of how societies manage its scarce resources (Mankiw, 2001), (scarcity in this context relating to the finality of a resource rather than an overall lack of it).

Economic models and theories of understanding have, and still are being created to help understand how these scarce resources can be maximised on all levels of scale, from micro to macro. The reasons for this are twofold; firstly, in order that we can understand the underlying phenomena of market interactions that occur every day within a free market society, and secondly, so that we can create policies and tools that will help to maximise our overall utility with the scarce resources that we have. Given that economics has this dual role as both descriptive of society (known as positive economics), and prescriptive of society (or normative economics), it (and its many sub-theories) clearly play a linchpin role within policy understanding since it allows policy makers to not only understand what market activities are occurring, but also, (to some degree) how they can be adjusted to produce a desired output.

All economics therefore looks at trying to understand market interactions between actors and create theories about how and why these interactions take place, what differs between theories however, is the assumptions that are made about these actors and how they maximise their utility.

Within the work of this thesis, many of the assumptions are based upon an evolutionary economics understanding of the market for reasons that are explained later within this chapter however for context, a brief overview of the current 'mainstay' economic theory known as neo-classical economics is given to provide both a context from which to address evolutionary economics and also as a background to the subject of economics itself. Ultimately, both theories hold strong truisms which can be drawn upon to analyse different scenarios and questions based on a certain level of appropriate selection.

Mainstream economics (or neoclassical economics as it is also called) is in fact the combination of two separate theories of economics, that of Keynesian macro economics with existing microeconomic, neoclassical theory. As a theory, it works under several strong premises that are used to build mathematical models (such as Roy Weintraub's 'General Equilibrium Theory') of interaction among agents and thus produce useful insights (Mankiw, 2001, Krugman, 2003). The various premise under which these models are built are in most cases very much sound in principal and application however the main split between neoclassical economics (particularly at a micro and meso level) and evolutionary economics is the fact that some of these primary assumption themselves are made. Evolutionary economists would argue that markets themselves are far more dynamic, stochastic and heterogeneous then neo-classicalists allow for with constantly changing inputs which are as a result, constantly 'churning' the activities and focus of the market. As Freeman puts it: "The fascination of innovation lies in the fact that both the market and the technology are continually changing. Consequentially there is a kaleidoscopic succession of new possibilities emerging"(Freeman and Soete, 1997).

Evolutionary economics has its genesis in the works of Alchian, who in 1950 published; 'Uncertainty, Evolution and Economic Theory' in which he suggested a new approach for economic analysis that 'embodies the principles of biological evolution and natural selection' (Alchian, 1950). Much like Darwinian Theory, the evolutionary theory of economic change suggested businesses (as with biological species) go through a process of variation (mutation), selection (success) and retention (growth). In this approach, since businesses do not have certain foresight of where profit maximisation lies, (i.e. what business decisions will be most profitable) they must adapt through trial-and-error to discover the most successful way forwards.

This theory was then amalgamated with early innovation theory (Schumpeter, 1934), ‘bounded rationality’ (Simon, 1957) and processes of learning (Arrow, 1962) (all discussed further within this chapter) by the notable economists Richard Nelson and Sidney Winters, in what has become considered the founding book on Evolutionary Economics; An Evolutionary Theory of Economic Change (Nelson and Winter, 1982).

Following on from this, Nelson and Winter, (and evolutionary economists in general) argued that neo-classical economics fundamentally oversimplifies assumptions made for modelling of (market interaction) in the following major ways for both micro, meso and indeed macro economic scenarios (Nelson and Winter, 1982):

- Markets always reach equilibrium within analysis. Therefore either empirical observations fed into models are *at* equilibrium state or, (through modelling) will in time *reach* equilibrium whereby the price of a product is set by the static intersect point of supply and demand. Evolutionary economics stipulates that, although this may seem to be the case in some scenarios, there is in practically, never a point of permanent equilibrium within a market as advances in technology and changes in both consumer choice and availability of product (among other factors) mean that the market should always be thought of as a dynamic and constantly changing process.
- Heterogeneity is often considered irrelevant. That is to say; modelling is always done with a ‘representative individual’ and all individuals are considered to be ‘the average’ for the demographic being modelled. This does not therefore allow for the multitude of different individual preferences and trade-offs that have to be made when deciding to purchase any particular good (such as a car). There can therefore, in neo-classical understandings, often be a ‘Pareto optimised’ market, (one in which the market runs at such an efficiency that no agent can become better off without detriment to any other).
- All agents are considered fully-rational and without bounds, having complete knowledge of the market at any one time. This is rather than practicably working under limited knowledge, (with regards to both the market and the product itself) limited competence (relating to agents ability to successfully identify, process and absorb the correct knowledge) and an often limited timeframes for decision making of market choices (under what is referred to as ‘bounded rationality’ (Simon, 1957)).
- There is little if any interaction among agents, that is; all agents act independently. Oblivious of social fads and phenomena such as the dynamics of increasing returns, which therefore prevents an appreciation of phenomenon such as the influential

actors, tipping point phenomenon and the multitude of fads and crazes from i-phones to children's toys.

It should be stated of the above points that neo-classicalists are not oblivious to such phenomena as 'tipping-points' or dynamic market states, and (as with evolutionary economists who have taken specific neo-classical assumptions to explore an economic phenomenon) many have grappled with methods for understanding such occurrences, however; where neo-classical philosophy and evolutionary economics differ is in the centrality of positioning that these assumptions take.

Evolutionary economics additionally plays a particularly important role within renewable energy policy as it addresses long term technology development and selection policy from a less laissez faire perspective, helping policy makers 'fill the shelf' with technology rather than simply allowing the market to select technology 'from the shelf' (Bergek *et al.*, 2008b, Sandén and Azar, 2005).

2.3 Innovation Theory

2.3.1 A Definition of Innovation

If evolutionary economics can be thought of as a Darwinian approach to market interactions, then innovation theory could well be seen as the theory of natural selection for them. Defining what exactly innovation *is* however has been a point of mild contention within innovation studies arguably since it began to receive academic attention in the early 20th century. Our modern understanding of the term can be credited to the Schumpeter who, in his 1934 publication, A Theory of Economic Development defined innovation as:

- "The commercial or industrial application of something new – a new product, process, or method of production; a new market or source of supply; a new form of commercial, business or financial organisation." (Schumpeter, 1934)

This broad definition covers almost any alternation within a market however, since then various economists and academics have both re-defined the term and refined its meaning. Jacob Schmookler, in 1966 defined innovation somewhat more gracefully as:

- “A two-sided coupling activity, the blades of a pair of scissors: On one hand, the recognition of potential market for a new product or process, on the other, a technical knowledge that may be general or new knowledge as the result of original R&D. Experimental design, trial and production and marketing involving matching the technical possibilities and the market.” (Freeman and Soete, 1997, Schmookler, 1966)

This was refined still further by Giovanni Dosi who later argued:

- “Innovation concerns the search for, and the discovery, experimentation, development, imitation, and adaptation of new products, new production processes and new organizational set-ups.” (Dosi *et al.*, 1988)

In more recent years, innovation has become thought of in the more specific context of the commercialisation process within business and possible reasoning for this is explored later within this chapter. Fagerberg however suggest that innovation is;

- “Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice.” (Fagerberg *et al.*, 2005)

The important element to note here is that; innovation is the *commercial or industrial application* of something that has been invented (i.e. the attempt at diffusion of an invention (Dosi, 1993)). With this in mind, an understanding and focus on innovation and how it occurs becomes more than the object orientated concerns of a singular product, process or commercial change but, like the ripples on a pond that occur from the throwing of a stone, needs to widen out into the context of the diffusion process itself, effectively bridging the boundaries from a specific technology orientation towards the economic and societal understanding that is required for a full appreciation of the diffusion process within context. Joseph Shumpeter’s early works emphasised three fundamental characteristics of the innovation process: The high levels of uncertainty that are inherent to the entire process, the requirement for innovators to ‘move quickly’ in order to gain competitive advantage and finally, an acknowledgement that there is always a social and market inertia towards change, and in that respect, innovation itself (Fagerberg *et al.*, 2005, Schumpeter, 1934).

Any practitioner of innovation studies however would be negligent were they not to assess the many characteristics of the innovation itself if they were to have some idea as to the type of diffusion process that would be expected. As with the shape and size of the stone in the pond, so the characteristics of the innovation can tell us a great deal about the process of diffusion that will likely occur.

There are many different characteristics of a particular innovation itself when thought about in the above context. Shape, cost, application, time, (if it is a process) and other codifiable characteristics of an innovation are fairly self explanatory however some properties of an innovation relate to its relationship to humans, implications to, and diffusion characteristics upon the existing market landscape or its new market. These features make up what has been referred to as the ‘script’ of the innovation (Law and Bijker, 1997) and some of these features are outlined below:

- Novelty: How radical an innovation is relates to the extent to which the innovation pushes along the progression of a technological paradigm. A highly incremental innovation may be one which is barely noticed by the end user such as the material change of a small component within a product or a slight difference of processing within a finance department’s activities. These innovations, although usually ‘smaller’ in nature, (and typically allowing less economic opportunity of reward) tend to be far more frequently implemented and often act as the ‘polishing’ of many radical innovations over time. A radical innovation by contrast will be one that substantially increases the value of a particular innovation, (usually through an increase in performance characteristics). These radical innovations will often be associated with a disruptive change to the overall characteristics of the market in which they operate.(Freeman and Soete, 1997, Fagerberg, 2003)
- Disruptiveness: An innovation’s disruptiveness is a measure of how much it deviates or reinforces the trajectory of the current innovation system’s paradigm. That is to say, non-disruptive technological innovations will de-facto, be a pro-incumbent one in which ‘business as usual’ continues.
- Complexity: An observed characteristic of much incremental innovation is that throughout time, existing innovations generally become increasingly more complex. Ever increasing competition of certain innovations has lead companies to higher levels of R&D activity and thus more formalised organisation of their innovation activity. (what Carlsson referred to as ‘scientification,’ (Carlsson and Stankiewicz, 1991)) Highly complex goods such as pharmaceuticals tend to require larger R&D resources, more sophisticated innovation deployment procedures, (such as testing standards) and wider knowledge bases then those of less complexity.

- Appropriability: Appropriability refers to the 'imitate-ability' of an innovation. That is, the levels to which others can reproduce the innovation. Some innovations have a high level of tacit knowledge embedded within them such that replication is extremely complex, (such as fuel cell, pharmaceutical or software technologies). Certain societal characteristics also protect appropriability such as patents, lead times and complexity of a good (coca-cola with its 'secret recipe' may be considered a good example of this).

One feature of these qualitative characteristics of innovation that should be noted is that they are *proportional to both the scale and proximity of the system in which they are being observed.* For example; a radical change in halogen lighting technology may well be very disruptive within its sector however to the automotive industry it will produce a 'spill-over' incremental change to the performance of some cars which are fitted with these lights. Likewise, a very disruptive change within the hard drive technology sector will have a far less disruptive influence upon the technological paradigm of the home computer market as a whole.

Most current innovation literature now tends to centre on the commercialisation of a product, process or business model. Schumpeter's 'source of supply' and 'exploitation of new markets' have received less and less focus as individual innovation concepts themselves and this is most likely because our understanding of the innovation process has itself evolved greatly over the last century. Shumpeter originally focussed heavily on the entrepreneur, (be it an individual as in Schumpeter Mark 1 or a large firm as in Schumpeter Mark 2 (See entrepreneurial theory, section 2.3.8f within this chapter)) as the sole innovator and champion of change within the market, current theory however leans towards a much wider focus on systemic innovation in which the entrepreneur is the agent, (or seed) of innovation however the system in which the innovation occurs, (including the market, supply chain, laws and even wider societal perspective itself) is not only intrinsically linked to the characteristic of the innovation but is vital to the successful emergence and diffusion of the innovation. The broadening of focus within innovation literature has led to an explosion of new literature and ideas, searching for the holy grail of innovative understanding which answers the question: 'What makes innovations succeed or fail.' This literature, has placed innovation within wider and wider embedded circles of understanding as it becomes ever clearer that external factors have an influence upon both the innovations success and the form of innovation itself. As a result of this, Shumpeter's market interactive conceptions of innovations (i.e. source of supply and exploitation of new markets) have been somewhat split from innovation theory. This has been due to a) their different generalised characteristics from other forms of innovation and b) their individual study having been amalgamated into the innovation systems and diffusion process itself.

Previously 'outside of system' elements were once seen as the 'dark matter' of innovation diffusion, (lacking properties of inertia or viscosity to social change). More commonly now, the boundaries of innovation systems are seen as inclusive of wider communities of specialists within the field, public perceptions and supply chains that return all the way to the material source.

In the following section (2.3.3), the varied literature published on innovation systems is explored which focus upon differing boundaries to help conceptualise the process of innovation and diffusion as it occurs within situ. After this we shall look at some of the many complimentary studies that help to explain and explore qualities of different innovation systems.

2.3.2 The History of Innovation Systems Theory

The history of Innovation was most notably outlined by Roy Rothwell in the early 1990s when he suggested that models of innovation systems had evolved from the early 50's until the (then current) 1990s through five distinct stages (Rothwell, 1993). Initially, between the 1950s to mid 60s, innovation was seen as a simple and linear process of R&D that the market accepted and embraced as technological progression. This model fitted with the 'Fordism' model of mass-production and mass-consumption that flourished during this time (Allen and Thomas, 2000). During the 1960s to early 70s this dynamic of technology push onto mass market switched to a responsive innovation industry, (R&D sector) focussed towards the market's pull itself. The second generation model was still linear but the search heuristics of innovation were now guided by the marketplace. The third model, from the early 70s to the mid 80s was an initial fusion of the previous two. It highlighting what technology was becoming ever increasingly capable of doing and how this could be coupled to potential user requirements. Although simple feedbacks were present, this model was still essentially linear in nature and is perhaps well exemplified by Schmookler's quotation on innovation earlier in this chapter (2.3.1). The fourth model saw the introduction of parallel developments of products within the same firm and drew upon the Japanese model of strong links towards the supply chain and lead customers (similar to what Carlsson refers to as 'prime movers' (Carlsson and Stankiewicz, 1991)). This model was seen as effectively encompassing the wider set of stakeholders within the supply chain periphery while still retaining a linear (albeit with 'parallel paths of progression') view of the innovation itself with ever increasing feedbacks into the process. The final model outlined by Rothwell, being entered into in the 1990s, an extension of the parallel model; incorporates elements of 'lean innovation' which relate to flexibility of production and features such as 'just-in-time' procurement based on a Japanese case study. This last stage also marked the genesis of modern innovation systems thinking with the coining of the; 'National Systems of Innovation' concept and the wider analytical approach that this brought about as outlined below.

Rothwell's observations showed that our concept of innovation, which started as an 'internal R&D process' in the 1950s has become ever increasingly sophisticated and outward looking in its understanding. Although *innovation systems* literature itself did not occur before Lundvall's 1985 seminal paper; Product Innovation and User-Producer Interaction (Lundvall, 1985) a clear understanding of the wider framework of context in which innovations occur was already emerging within society. This paper stopped just short of the "national systems of innovation" concept, however it referred to the practice of innovation within "national systems of production" (a distinction that although might at first be seen as simply linguistic rather than conceptual, was in fact highlighted as different by Lundvall himself in later work (Lundvall *et al.*, 2002)). This overall development was non-the-less interesting as it shows that innovation system literature initially held a 'positive economic' position (i.e. descriptive) of what was occurring within society and specific case studies. Since then however, Innovation systems (IS) theory has overtaken the natural industrial evolution of our understanding and moved (albeit cautiously and with an empirical evidence base from which inductive findings have been drawn), towards a more normative economic position (i.e. describing what we should do).

Following on from Rothwells work, modern innovation systems have moved towards ever broader and more complex models, attempting to include externalities into systems literature which are believed to be influential enough to have a strong affect on both the innovation's process of maturity and the diffusion itself. Edquist suggests that the first real attempt at this was done by Freeman in 1987 who defined 'national innovation systems' outlining the importance of structural agents such as the government, universities and other stakeholders as important for the innovation process (Edquist, 2005, Freeman, 1987). At around this point is when our understanding and explanations of the innovation process was effectively 'de-coupled' from the initial innovating firm and it's embedded vertical supply chain actors (such as customers or suppliers). Although these stakeholders have key influences and roles within the process, innovation theory began to see innovation within wider industry, sectoral, national and even international context as concepts of globalisation and wider governance (such as the EU and UN) had an ever increasing influence upon the process of innovation.

Since then, and particularly over the last decade, there have been many attempts to identify what factors are relevant to innovation and how they might affect its successful diffusion. In fact, there is now a growing body of literature on the comparative strengths, weaknesses and focuses of different innovations systems literature itself (Chang and Chen, 2003, Fagerberg, 2003, Edquist, 2005). One of the most notable recent 'splits' in conceptual understanding have been the distinction between the 'multi-level perspective' (MLP) view of innovation (proposed by academics such as Geels and Raven) and the 'dynamic' view (held by academics such as Carlsson and Bergek). These and other current theories of innovation systems, shall be explored further in the following section.

2.3.3 Types of Innovation System

2.3.3a National Innovation Systems

Probably the most widely written about and commonly used form of innovation system is the National Innovation System approach (NIS). This was not only the first innovation system to emerge within literature but was the genesis for many of the strong modelling assumptions used in latter systemic models. It also has obvious political convenience in that it concentrates on the nation state as the locust of innovation. There are very good reasons for this to be a natural boundary selection of the system. Laws are an obvious factor that influence the emergence and diffusion of innovations but so too are cultural norms and values, linguistic properties and geographical factor conditions.

Although there is no definitive definition of the NIS itself, the OECD, 1997 publication 'National Innovation Systems' states that: "The concept of national innovation systems rests on the premise that understanding the linkages among the actors involved in innovation is key to improving technology performance"(OECD, 1997). There are many other writers on national innovation systems however all of them share the common focus on national boundaries as their 'system cut-off' point.

No operational 'model' for understanding NISs exist, the rich vein of NIS literature however highlights many key elements that distinguished it from its precursor linear models (detailed below) in which innovation was seen as a direct input-output measure from R&D expenditure to product sales and employment.

As stated in the above section, (2.3.2) the first real defining of national systems of innovation was done by Christopher Freeman in 1987 (Freeman, 1987). In his book, Freeman investigated the case of Japanese industrial re-development, looking specifically at how, with the large economic problems resulting from the second world war, the Ministry for International Trade and Industry (MITI) as well as a strong industrial culture managed to become a world economic powerhouse. This was mainly done through both a comprehensive and encompassing level of policy control over factors that affected Japanese industry, an adaptive and creative working culture that embraced better methods of production and supply and the unhindered impetus for change that was required.

In 1992, two defining books were published specifically on national innovation systems, mainstreaming the concept of the innovation to a far wider range of policy makers, academics and businesses alike.

The first, Nelson's book: National Systems of Innovation: A Comparative Analysis, focuses on just that, a comparative assessment of 15 different country's national innovation approach (Nelson, 1992). This assessment, based very strongly upon case studies (in a same style as Porter's earlier (although more mainstream) work on economic competitiveness of countries: The Competitive Advantage of Nations (Porter, 1990)) attempts to describe what occurs based upon empirical evidence & inductive reasoning. Many of the findings and conclusions are broad-based and relate to generalised types of countries such as: "For firms based in high-wage countries, being competitive may require having a significantly more attractive product or better production process than firms in low-wage countries".

The second book by Lundvall, (National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning) on the other hand uses statistical data on R&D spending, growth rates, patenting and other indicators to create a more theoretical framework that focussed on understanding some of the less fiscal elements of innovation systems (Lundvall *et al.*, 2002, Lundvall, 1992). These include the importance of trust and tacit knowledge within the innovation process as well as the importance of different forms of learning to the innovation system. Additionally, Lundvall emphasised and refined some of the following revisions within the NIS approach:

- The importance of backwards linkage in the form of flows of information user sectors.
- The introduction of different forms of learning from interaction ('by doing' and 'by search) (see section 2.3.8b later in this chapter) as well as competence building.

- The distinction between industrial subsystems at different stages, as seen from a 'life cycle' perspective.

A central focus of the NIS approach (and a foundation by which all current innovation systems agree), is on the value of knowledge flow and an acknowledgment that this is neither a linear process nor one that is internal to a company. Rather, there is a 'web of knowledge' that exists within a sector, between firms, academia and other stakeholders in the form of collaborative work, patents, publications, formal teaching, labour mobility, market research and other knowledge diffusing methods. This knowledge also has with it various characteristics such as a tacit/codified nature which are discussed in section 2.3.8a of this chapter. From this understanding, policy implications imply that the promotion of innovation requires more than a focus on R&D funding but rather, the facilitating of knowledge flows and information within a sector to allow innovators to gain access to the knowledge of both market demand and technological capability. NIS also builds on the evolutionary economics premise that agents have bounded rationality which is intrinsic to our understanding of knowledge flows as it suggests that there must be a concerted effort in ensuring that knowledge diffuses throughout a sector where applicable.

2.3.3b Socio-Technical Innovation Systems

Much work on Socio-Technical Innovation Systems (ST-Systems) has been done by Geels and Berkout (Geels, 2005, Geels, 2004, Berkhout *et al.*, 2003). Geels suggests that innovation systems should not only encompass the production, diffusion and use of technology, but also the 'linkages between elements necessary to fulfil societal functions' (such as trains, communication networks etc.). ST-Systems as a form of analysis, predominantly take a wider assessment of a systems embedded economic and social surroundings (Smith *et al.*, 2005). From a historical perspective, ST-Systems are possibly the most broadly inclusive form of innovation systems analysis (with the possible exception of Large Technological Systems) since they try to encompass a higher number of contributing elements that affect upon an innovation then other forms of systemic analysis. This has both positive and negative connotations; on the positive side, in taking into account the larger scope of 'inputs' that affect an innovation and it's diffusion, ST-Systems could be said to be both more 'comprehensive' in their coverage and less susceptible to changing externalities over time. On the negative, this wider scope creates problems of operational practice, (i.e. how to practicably conduct societal wide forms of analysis) and the key ST-Systems literature is theoretically heavy, without specific focus on case studies or examples (Geels, 2004, Berkhout *et al.*, 2003, Smith *et al.*, 2005).

Some of the key elements Geels focuses on include 'rules' which relate to an extended form of institutions in that they are governing elements of peoples behaviour. Rules differ in that they include non-legally binding behavioural motivators as well as legally binding ones and are thus broken into three elements:

- Regulative rules, which are in effect similar to 'institutions' and can be thought of similarly, as the laws, standards and regulations (Bergek et al., 2008a, Malerba, 2002).
- Normative rules, which relate to societal and group norms of practice, senses of duty or authority and other 'status-quo' beliefs about the system.
- Cognitive rules, which are based on deep-set values within individuals such as our beliefs and perception of 'right and wrong'.

These rules are in fact fused into what is described as 'regimes' in which collective groups, (such as a scientific regimes or political regimes) will operate, holding their own specific overall cognition and agenda. The interesting focus of Geels however is that different groupings can be linked by similar *rules* and thus Geels suggests that 'meta-coordination' of different groups can occur through a process of modifying or dispelling these rules at the lower level than the regime.

ST-Systems is also a classical example of 'multi-level perspective' (MLP) innovation system in that Geels maps out the transition of technology system from niche stage 'up' into the socio-technical regime (built out of rules) and its final influence and response to the wider 'socio-technical landscape', the widest stage of understanding that relates to societal wide aspects such as positioning of cities, electrical infrastructure etc. See Figure 2 below for Geels' graphic representation of this.

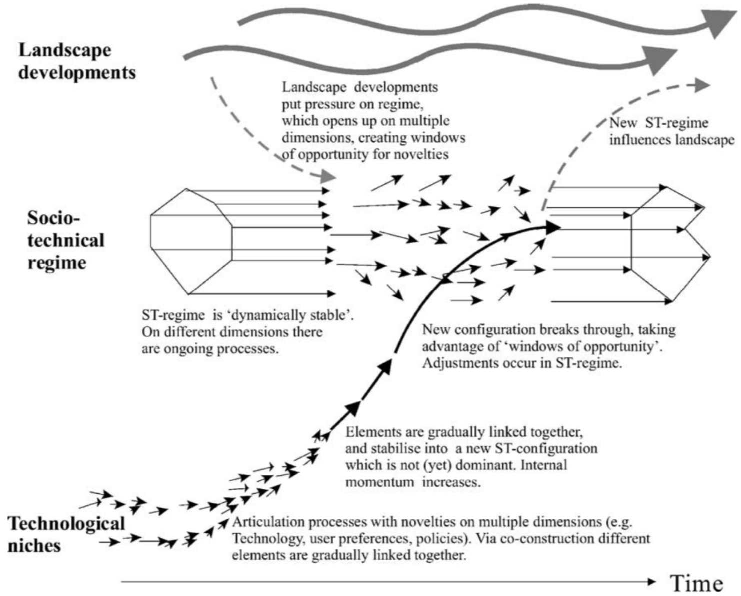


Figure 2: Geels' dynamic multi-level perspective on innovations.

This layered approach has aligned Geels' work with strategic niche management studies and the concepts/tools required for bringing technical niches into fruition and embedding them within (or in many cases replacing) the status-quo dominant regime. See the Transition and Niche Management section (2.3.7a) of this chapter below for more detail.

2.3.3c Large-Technological Systems

At the same time in which Freeman was publishing his first findings on National Innovation Systems, Wiebe Bijker and Thomas Hughes published The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology, a more sociologically influenced perspective on technological change (Bijker et al., 1987). Following on from this, Mayntz and Hughes edited the published work: The Evolution of Large Technological Systems, creating a conceptual framework which sought to assist in the understanding of utility scale technologies (such as power or gas distribution) and the process of gradual change under which it operates. (Mayntz and Hughes, 1988)

Mayntz and Hughes broke large technology systems into five (interacting) key components: Natural resources, organisations, physical artefacts, scientific components and legislative artefacts. These components make up what they described as the "complex and messy" system in which large technologies occupy. These socially constructed components fulfil differing functionalities and play roles within the system, the changing of which would almost always having a knock-on effect upon other components.

2.3.3d Cluster/Regional Innovation Systems

Phillip Cooke is generally cited as the first founder of Regional Innovation Systems (RIS) and his initial work was provoked by an increasing interest in (industrially supportive) regulation which he claimed was predominantly being focussed on the regional scale rather than the state (Cooke, 1992). The reason for this interest was considered to be the 'post-Fordism' recognition that the assumed link between mass production and mass consumption was no longer valid in certain countries or industries, justified by various regional cases where the following commonalities occurred:

- Dense clusters of small firms or a mix of large and small firms closely integrated by networks.
- Higher densities of skilled workers then in other regions.
- Innovative behaviour (dependent upon highly-developed research and scientific infrastructure.)

(Cooke, 1992, Braczyk *et al.*, 1998)

In response to this finding, Cooke identifies three models of regional clusters and three (un-associated) forms of RIS governance. These three forms of clusters are: local, interactive (Balanced between both small and large firms) and globalized, (large company dominated). Additionally, the three forms of governance for regional innovation activity are: Grassroots (locally generated), network (coordination is enacted locally, nationally and internationally) and dirigiste, (centrally planned). These two sets of combinations form a matrix in which nine possible RISs are formed holding corresponding characteristics related these two factors. (Braczyk *et al.*, 1998, Cooke, 1992, Cooke, 2006)

One of the most prominent works on explaining this phenomenon of industrial 'clusters' (from which much regional innovation theory builds on) was done by Porter whose work; The Competitive Advantage of Nations redefined many national industrial policies and was widely hailed as one of the most comprehensive examinations of industrial growth and economic policy in recent times (Porter, 1990). Although not strictly falling within regional innovation systems (which had not been coined at its time of publication) Porter's work identified the strength of industrial 'clusters' of companies with properties of high internal competition, regionally localised competitive supply chains and strong local markets as having strong self dynamism to compete at international levels. He also created a conceptual framework known as the 'Diamond of Determinants' which is outlined in Figure 3 below.

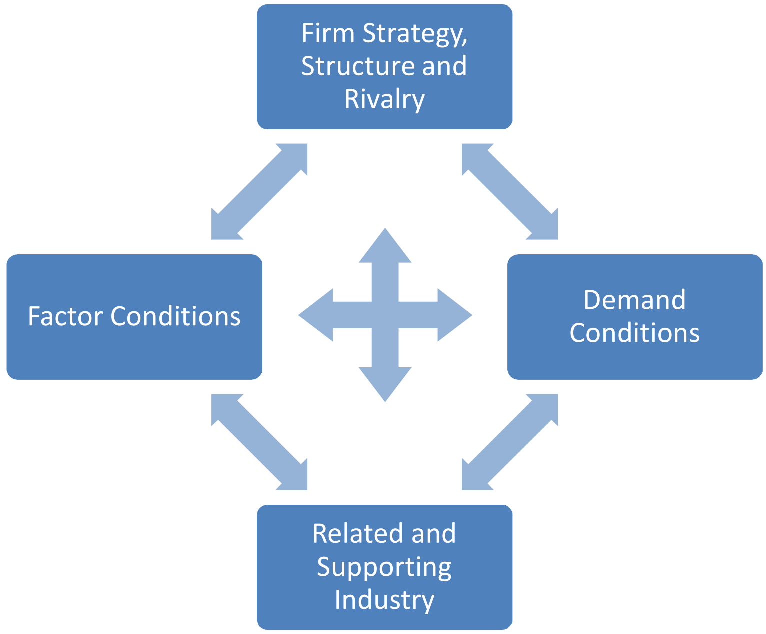


Figure 3: Porter's 'Diamond of Determinants'

In this model, Porter describes these determinants as: Firm strategy, structure and rivalry, factor conditions, (the human, physical, knowledge, capital and infrastructural conditions around which a company operates), demand conditions and finally related and supporting industry. Porter explores the highly interactive nature of these determinants and how alterations of one determinant can affect not only another determinant within the same sector but also, in many cases, a different sector all together.

2.3.3e Sectoral System of Innovation

Sectoral Systems of Innovation (SSI) present technological sectors as having strong properties of commonality while suggesting that all sectoral systems are different and that approaches for analysis must be done with a clear understanding of the technology and its characteristics (Chang and Chen, 2003).

Breschi and Malerba define SSIs as the; "system (group) of firms active in the developing and making a sector's products and in generating and utilizing a sector's technologies" (Breschi and Malerba, 1997). As with Technological Innovation Systems (TIS)(section 2.3.3f), SSIs regard innovation as being able to hold strong international dimensions and focus not on the country but on the interactions of firms. In this respect, SSI is very closely related to the TIS approach with the main divisions being in a) TIS's clearer analytical model and b) SSI's slightly higher focus on the regional dimensions of innovation (such as geographical clustering) (Bergek *et al.*, 2005, Breschi and Malerba, 1997).

The most developed framework of the SSI comes from Malerbra who identifies 7 key elements as outlined below:

- Products: Simply relating to the primary product or service of exchange within the sector.
- Agents: The firms, public bodies, universities, financial institutes etc.
- Knowledge and Learning: The underlying base of knowledge that the sector relies on and supports the production, diffusion and research activity of the sector.
- Basic Technologies, inputs, demand and the related links and complementarities: This element is similar to the vertically and horizontally related sectoral 'spill-over' or 'free utility' (Carlsson *et al.*, 2002, Scitovsky, 1954). It suggests that these inter-sectoral relationships are usually bidirectional and multi-faceted in that it includes knowledge, demand, innovation production and sale utilities.
- Mechanisms of interaction within and outside of firms: Unlike the above element, this level of interaction is focussed on the individual actor rather than the 'sector-sector' relationship.
- The process of competition and selection: The primary elements of market variation and consumer selection that greatly affect industrial dynamics.
- Institutions: As outlined in various other sections of this chapter (2.3.3f & 2.3.3g), Institutions relates to the rules, laws, standards and established practices within the sector.

(Breschi and Malerba, 1997, Malerba, 2002)

2.3.3f Technological Innovation Systems

Technological Innovation Systems (TISs) first appeared as a form of analysis in 1991 when Carlsson and Stankiewicz published; On the nature, function and composition of technological systems (Carlsson and Stankiewicz, 1991). In this paper they suggested that the development potential of countries was related to the number and success of technological innovation systems within it, while acknowledging that these systems may not be confined to either national or other geographic borders. They defined Technological Systems as:

> "A dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of

Although they did not give an operational method for analysis of such systems, their work identified key attributes that were suggested as being:

- Economic competence: A company's ability to develop and exploit new opportunities. (This is a concept closely related to a company's bounded rationality (Nelson and Winter, 1982)). This includes sub-elements such as individual's abilities to acquire, process and consolidate information as well as coordinate and creatively respond to market changes.
- Clustering of resources: The perceived necessity for a clustering of industries that Carlsson argued has been historically required for innovation to occur. In this respect, Carlsson advocates heavily, the requirement for (both vertical, horizontal) networks as an important prerequisite for innovative activity to occur and uses the term 'development blocks' to identify the 'untraded interdependencies' among sectors, technologies and firms which result from this clustering activity and the work of exceptional entrepreneurs. These development blocks (originally coined by Dahmen (Dahmen, 1950)) are 'dynamically stable' self enforcing networks of knowledge and market stimulation.
- Institutional infrastructure: The need to reduce 'social uncertainty' and mitigate potential conflicts through the introduction and enforcement of institutions. (In this context, institutions is defined as both laws, regulations or other 'economic' institutions and also informal, implicit institutional norms (similar to Geels' 'rules', see Socio-Technical Systems, (section 2.3.3b) (Geels, 2004)). Legitimacy is highlighted as a key requirement for institutional alignment to become successful.

The key distinguishing features that this early formation of TIS held from National Systems of Innovation, were the specific focus on the micro and meso-economic factors (such as the individual entrepreneur, firm, their competencies and networks) that are central to their formation and their lack of geographical boarder. Indeed, when a national boundary layer is used, the technological innovation system identified by Carlsson did in fact have many aspects in common with its predecessor, the NIS as outlined by Nelson, (Carlsson and Stankiewicz, 1995, Nelson, 1992, Nelson, 1988)

In 2000, Jacobsson & Johnson built on this work by creating the first rough work on a framework of analysis (Jacobsson and Johnson, 2000). In this, they identified some of the key structural components (or elements as they described them then) of the technological innovation systems that they argued needed to be both separated and identified were important occurrences within a TIS to be understood. These elements were:

- Actors and their competencies, specifically ‘prime movers’ who they identified as those agents who have a strong level of influence upon the development and diffusion of a new technology.
- Networks, referring to the formations of agents who assist in the diffusion of knowledge. Jacobsson also identifies the value of embeddedness within a network to the actor.
- Institutions. Following on from Carlsson’s earlier definition, institutions define both formal and social rules that constrain, direct and dictate certain behavioural norms. (Carlsson and Stankiewicz, 1991)

Without defining what actions these elements were required to carry out, (as was later the case) Jacobsson and Johnson still identified some of the factors that they non-the less argued, led to failure of adoption and diffusion for specific technologies within a system. These included functions such as ‘poor connectivity’, ‘local search processes’ and ‘legislative failure’.

In 2001 Liu and White, referring to Carlsson’s 1995 book, came to a similar conclusion that the catalysts of change and thus focus of analysis within innovation systems literature, should be built upon from the individual elements of the system (Liu and White, 2001).

One of the interesting factors of Liu and White’s paper is that they maintained, (and defended) a national system boundary due not only to the political, legal, regulatory and cultural importance of the national setting, but also (echoing Nelson) due to the primary concern that policy makers have over both local and national outcomes (Nelson, 1992). Additionally, since their focus of analysis was a longitudinal comparison of China pre- and mid-transition, from a wholly structuralised and centrally planned economy towards a transitional free market, Liu and White took a holistic evaluation upon the activities of state overall rather than focussing on one specific technology group.

A key contribution to TISs literature that Liu and White introduced was functionality (or process) framework (although somewhat contested since Johnson was working on a similar framework identified below): Appreciating the complexity and heavy level of analysis which would be involved in analysis of individual firms within a system, they suggested an aggregated analysis of collective organisation's behaviours from which larger processes within the overall technological system could be identified and monitored. These system level processes (which they referred to as 'fundamental activities') were identified and listed as; Education, Implementation, End-Use, R&D and Linkages and were complimented by the distribution of China's actors within the system that both influenced and took influence from their function as shown in Figure 4 below.

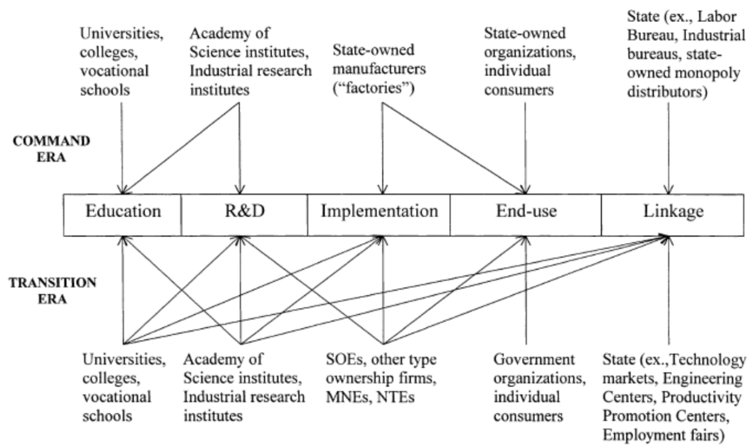


Figure 4: Liu and White's; Distribution of activity and primary actors in China's innovation system under central planning and since reforms.

At almost the same time to Liu & White's publication came out, Anna Johnson, (now Anna Bergek) wrote a conference paper that sought to synthesis many of the common thematic elements that were being discussed within existing innovations systems literature into what she described as 'functions' (Johnson and Jacobsson, 1998). This paper was itself a review of established findings that bought together and identified seven key functions that support the innovation. These functions were; *Supply Incentives* (i.e. the motivation that brings a company into engaging in innovative work); *Supply resource* (i.e. such as providing funding to the sector); *guide the direction of search* (i.e. influencing the direction of search within the innovation system); *recognised potential for growth* (i.e. the legitimating factor of the sector); *facilitate the exchange of information and knowledge, stimulate/create markets*, *reduce social uncertainty* (specifically with respect of internal conflict resolution between actors); and finally *counteract the resistance to change* (i.e. breakthrough technology lock-in from the status-quo system). Although loosely defined at the time, Johnson when on to refine these functionalities through various studies and papers (Jacobsson and Johnson, 2000, Johnson and Jacobsson, 2003, Bergek *et al.*, 2005, Bergek *et al.*, 2008a) into what is now the predominant model associated with Technological Innovation Systems .

Bergek's formalised definition of technological innovation systems was detailed within the 2008 paper, "analysing the functional dynamics of technological innovation systems: A scheme of analysis" (Bergek *et al.*, 2008a). This modifies and incorporates functionalities into a scheme of analysis outlined three years earlier by Oltander and Perez (Oltander and Perez, 2005). This scheme of analysis places the importance and contribution of functionalities within an analytical framework for assessing the overall health of the system in a logical 'step-by-step' approach as shown in Figure 5 below:

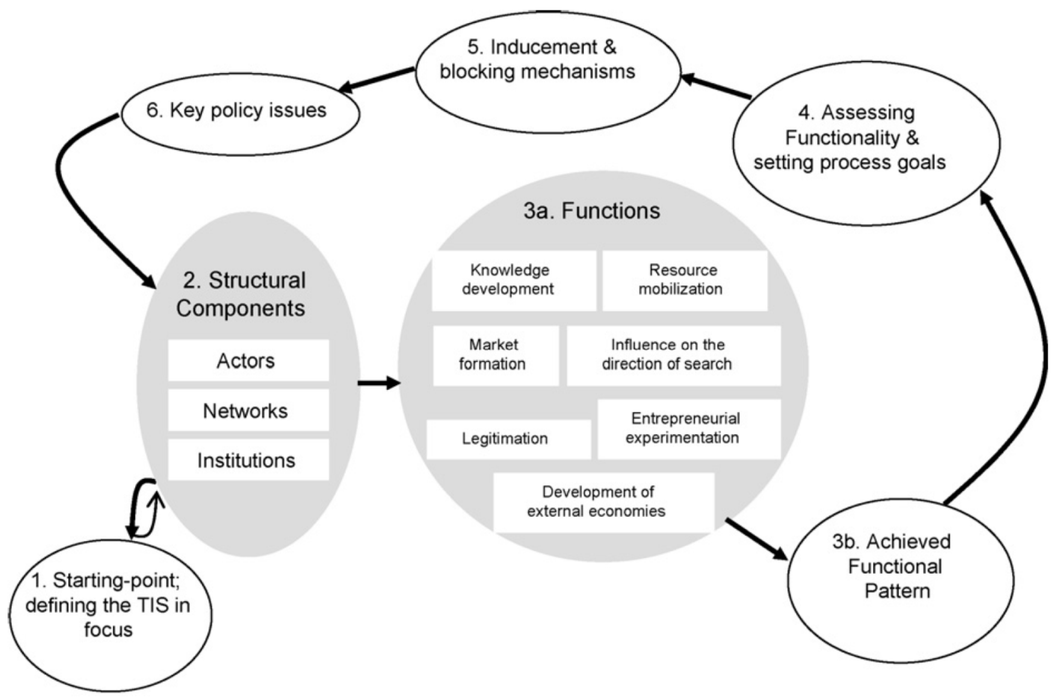


Figure 5: Scheme of System Analysis Adapted by Bergek (Bergek *et al.*, 2008a)

In this model of analysis, actors, networks and institutions (laws and regulations) are identified. Their contribution towards the various achieved functional patterns is then assessed on a function-by-function basis. From here, bottlenecks/reverse salients (i.e. blocking the full development or operation of a function) can be identified and policies put in place to rectify this.

2.3.3g System Functionality

Since Bergek, Lie, White's earlier contributions, various theorists have proposed functionalities that have fallen broadly into the categories outlined by Bergek above. The actual interpretation of these functions does differ in some cases but tend to have roughly similar themes in most. One of the key avenues of research being conducted on innovations systems is in understanding the many interactions between these functionalities and the apparent logical directions of influence that they have upon each other within a growing or declining system of operation (Bergek *et al.*, 2008b). As these functionalities play a key role within this thesis, below is an outline of each and what they denote.

Development of Positive Externalities

'Free utility' (Carlsson *et al.*, 2002), 'positive externalities' (Bergek *et al.*, 2008a) or 'external economies' (Porter, 1990) refers to the benefits that might be gained by an industry due to developments of another industry type outside of its own sector. That is to say, differing technology industries may be proximally close in terms not only of geographical locations, (such as physical industrial clusters) but ever more apparently in terms of both knowledge space and also value chains in which they act/interact. For example, both wave and tidal energy is often supported together, functionally however these technologies are different in their method of power extraction. Non-the-less, they share many elements of similarity such as marine engineering, the necessity for power take-off mechanisms and indeed the similarity of their stages of market development. Slightly further from the wave energy sector in terms of system proximity is the offshore wind industry which again shares many elements such as marine engineering, power electronics and foundation technology; however it is at a much more developed stage of industrial maturity and does not need to be as robust and survivable in sea conditions since most of its component technologies stand above the water level. Finally, power generation systems such as onshore wind, biomass and nuclear share very little with the wave energy sector from a technological standpoint other than their integration into the electrical grid system and the associated market competition. Positive externality, within this picture of system proximity, relates to benefits from certain sectors having spillover effects on systems nearby. Economists often highlight the importance of this proximity and of localised knowledge spillovers in facilitating innovation (Feldman, 1999).

Legitimacy

Legitimacy can be seen as the level of alignment between ones expectations of a technology system and its actual performance. Legitimacy varies up and down, (see 'technology hype curve' in section 2.3.7b) as a result of this expectation being either higher than the systems performance or lower. As Negro *et al.* says: Actors can de-legitimise technologies with respect to three dimensions; the performance of each unit, the potential and the proven functionality (Negro and Hekkert, 2010).

Legitimacy has a dual role in relation to actors: It can be thought of as the perceived level of expectation which a technology holds to an individual or firm (or the cognitive legitimacy). In parallel with this however, the active role of actors means that they can affect the legitimacy of a technology through a process referred to as 'legitimation' as Bergek *et al.* calls it or 'socio-political legitimacy' as Low and Abrahamson refer to it (Bergek *et al.*, 2008a, Bergek *et al.*, 2008b, Low and Abrahamson, 1997). It is therefore seen as a key function for both emerging, niche innovation systems and by implication the focus of political actors to help try and increase the legitimacy of a technology to assist in the development of the sector. Increased public, political and industry perceptions of legitimacy, (when done in conjunction with the underlying functionality of the technology), will assist in both the amount of new entrants into the sector, the amount of consideration a technology receives when regulations and laws are being formulated, the amount of public approval a technology receives and the general level of 'hype' that encompasses it. Geels (as well as Bergek to a lesser degree) discuss how three forms of 'rules' or 'institutions' (that is, the governing processes that affect system decision making such as are described below) are affected by legitimacy (see Socio-technical systems in section 2.3.3b of this chapter) in the following fashion:

- Regulative legitimacy, relating to the amount of weight in formalised, legislative decision making that the technology receives. This would include legal laws, regulations, protocols and other types of codified and 'enforced' institutions.
- Normative legitimacy infers the active morally driven expectations of the technology in so far as its future hopes and beliefs of expectation. This includes the 'search heuristics' under which the technology operates, the moral rationality for the technology and the idealisation of where the technology should move towards.
- Cognitive legitimacy, relates to the underlying (and non-agenda driven) perceptions and beliefs in the validity of the technology as held through different actors. It includes public and stakeholder perceptions or the expected operating performance of the technology.

(Geels, 2004, Bergek *et al.*, 2008b)

Knowledge Generation and Diffusion

Knowledge generation/development and diffusion is seen as central activity of the innovation process, and an extensive, multidisciplinary field of science in its own right that covers a spectrum of disciplines from philosophical epistemology and biological learning patterns to economic concepts and applications of learning. Current economic opinions on knowledge are explored in much greater detail later in this chapter (section 2.3.8). Within innovation systems literature however, knowledge development and learning commonly refer to both individual competence building and the formal scientific R&D process of invention and innovation refinement that occurs both within industry (mainly through the process of entrepreneurial experimentation), at universities or within other research institutes (Edquist, 2005, Bergek *et al.*, 2008a, Hekkert *et al.*, 2007).

With this said however, there are many forms of learning and knowledge generation that have typically been less associated with innovation systems literature. This may partially be something to do with the complex characteristics of some of these forms of knowledge which are hard to quantify and even harder to measure. They include such forms of knowledge such as; tacit skills, knowledge generation from artefacts and forms of learning such as "by interaction" and "by searching" which although sometimes stated, are often left un-explored (Dosi *et al.*, 2002, Rosenberg, 1982, Lundvall, 1992). A more expansive discussion on learning and knowledge types is discussed within the Knowledge and Learning Theory section (2.3.8) of this chapter.

Within network analysis, the amount of knowledge diffusion that an actor has within an epistemic network *must* be equivalent to the summated 'out ties' that an actor has (i.e. the literal valuation of knowledge that they are diffusing to the network) however this is problematic as it is mathematically identical to Hanneman's wider network description of 'influence' (Hanneman and Riddle, 2005). This later description however covers a range of networks, inclusive of purely 'social' network, (i.e. friends, politicians meetings etc.) in which the 'influence' identified may be much less formal than that of collaborative and constructive knowledge sharing itself. Since the network under analysisi within this thesis is purely epistemic, (see chapter 5, Methodology for more detail) the summated out-ties within this thesis shall be thought of as the level of know diffusion however it is acknowledged that this is a somewhat ambiguous refinement that could as equally be described as the formalised 'influence'.

Market Formation

Market formation is the process of establishment and consolidation that occurs between manufacturers, purchasers and users. This progression involves an increasing level of competence and ability by manufacturers or supplier to meet the demands of customers (Bergek *et al.*, 2008a). As this process occurs, there is a clarification and amplification of the customer's articulation of demand that results from the 'learning by using' of the innovation. As levels of trust form between supplier and user, a market structure begins to emerge at different levels within the supply chain.

This market formation can be seen as the increasing structuration of market activities similar to the transition of activities that Geels outlines from niches, into regimes and finally landscapes. As markets form their level of connectivity presses through these levels of hierarchy exerting ever increasing levels of control upon the wider socio-technical landscape (Geels, 2004).

Influence upon the Direction of Search

This functionality can be thought of as the opposite side of the coin from legitimacy in that it represents the source, level of and directionality of influence with regard to other stakeholder's perception of the system. This influence is bi-directional.

Firstly, it refers to the external influence upon companies and other potential contributors into entering into the system of operation (Bergek *et al.*, 2008a). "What factors influenced your university to start conducting research into the marine renewable energy sector" is an example question that pulls out this influence. These influences can be thought of as changes in influence that are projected 'outside' of the innovation system (or changes to the socio-technical landscape (Geels, 2004)) in that they affect actors who are not currently acting within the system but will most likely be on the periphery of it.

The second form in which there is an influence upon the direction of search is on the internal search heuristic within the problem solving (normally R&D led) community of the system. This can be related to the technology selection, preferred business model or geographic locating elements of those acting within the sector (Bergek *et al.*, 2008a). This second form of influence is closely linked to Dosi's notion of the 'search heuristic' (Dosi, 1993).

Influence upon the direction of search is closely linked to the legitimacy of the system however the two are different since legitimacy is related exclusively to the system, (without consideration of 'outside of system' options) and does not necessarily influence actors to enter the sector since it does not consider barriers-to-market entry, appropriability within the company or other factors. Likewise, the influence upon the direction of search for any particular firm is not exclusively related to the legitimacy of one particular sector, but will be related to a multitude of considerations not least of which being the legitimacy of other sectors 'competing' for their involvement. For example, the offshore wind energy sector may be undergoing a large increase in legitimacy as a result of public policy measures to install high levels of capacity within the UK however, if oil and gas prices are too high then the natural economic decision of jack-up-barge owners or marine engineering companies (the influence upon their perception of the most promising sector) will be to work within the oil and gas sector where the financial returns would be greater.

Materialisation

Materialisation is a straightforward concept that relates to the level of 'development of artefacts such as products, production plants and physical infrastructure' (Bergek *et al.*, 2008b). Within the wave energy sector for example, this can be most easily translated into the actual level of deployment of wave energy devices (in units or capacity rating) that occur. Materialisation is a relatively new 8th functionality to Bergek's model having been missing from the initial seminal work outlying TISs (Bergek *et al.*, 2005, Bergek *et al.*, 2008a).

Resource Mobilisation

In contrast to materialisation that identifies the outputs from the TIS, resource mobilisation tries to quantify the 'inputs' mobilised to assist in the development of the TIS. Specifically this can relate to the amount of finance being injected into the system (from grants, venture capital or other sources), the human resource (i.e. skills and personnel) and any other resources that may assist in the sectors development (such as jack-up barges mobilised from other sectors being used within the wave energy industry).

Resource mobilisation can be fairly non-specific and 'grass-roots' in terms of overall regional or wider sectoral development. What Porter refers to as 'factor conditions' (Porter, 1990) within his 'diamond of determinants' (See 'Cluster/ Regional Innovation Systems' section 2.3.3d), can incorporate generalised resources which benefit a wider range of industries. At the most aggregate, this could include infrastructural projects such as travel and communication systems however as systems become more defined (i.e. more specific in their function) more specific resources required to assist their commercialisation become apparent. For example, when thinking of only of marine innovation as a wider system, (i.e. ship building, marine renewables, marine leisure services etc.) greater port facilities could assist in increasing options and lowering costs. When looking at more defined systems however these benefits may not be as universal. The difference between 'factor conditions' and 'resource mobilisation' is that broadly speaking, factor conditions are usually defined as assistive to a wide range of sectors and encompassing a larger scope of endowments (e.g. a nation's scientific community, or its postal service), whereas 'resource mobilisation' is targeted specifically for the benefit of the sector in question (e.g. building a wave energy test centre).

Entrepreneurial Experimentation

Entrepreneurship is an essential aspect of the innovation process and is discussed further within the Entrepreneurial Theory section (2.3.8f) of this chapter. The act of experimental searching is the precursor to the realisation of innovation and this function identifies its amplitude of activity (although not as such its focus or direction which would come under the internal influence of the direction of search).

Experimentation occurs both within large organisations (in which the process of research and development is often more formalised and complex, what is referred to as 'scientification' (Carlsson and Stankiewicz, 1991)) as well as among smaller device developers in which the process of experimentation is far less likely to be identifiable or comparable due to the less formal format of the process. Identifying these different expressions of experimentation therefore requires different proxy indicators for experimentation. Bergek suggests: number of new entrants, number of different types of technology used, the character of the complementary technologies employed and the number of different applications (Bergek *et al.*, 2008a). In other established methodologies for identification of R&D activity these indicators may be different. The OECD Frascati manual (which provides indicators for innovation R&D statistics) suggest measuring; R&D personnel (i.e. how many person-years are expended), R&D expenditure and R&D facilities (libraries, labs, test centres etc.) as well as 'macro statistics' such as national gross domestic expenditure on R&D (GERD) and levels of international/global R&D collaboration (OECD, 2002). Freeman argues that these indicators do not in fact measure *innovation* itself but rather the level of scientification or formal R&D activity occurring without paying heedence to either individual entrepreneurial experimentation (i.e. that performed by Shumpeter's 'Mark 1' theory innovators (Schumpeter, 1934)) or actual innovative output (Freeman and Soete, 2007). Within Bergek's model however these measures alone are clearly not intended to be absolute measure of innovation and simply relate to the process of experimentation that needs to occur in order for innovation to happen.

2.3.3h Conclusive Remarks on Innovation Systems

Arguably, a reason why innovation literature exists on so many systemic levels is because they all share a level of validity in the influencing innovation and thus a synthesis of their understanding is required. As our understanding of the relationship between different system stakeholders, their knowledge inputs on innovation and their affect on that system have grown, so too has the overall systemic boundaries that are used to understand the process. Figure 6 below places innovation within the context of differing spheres of influence as amalgamated from the above innovation systems literature.

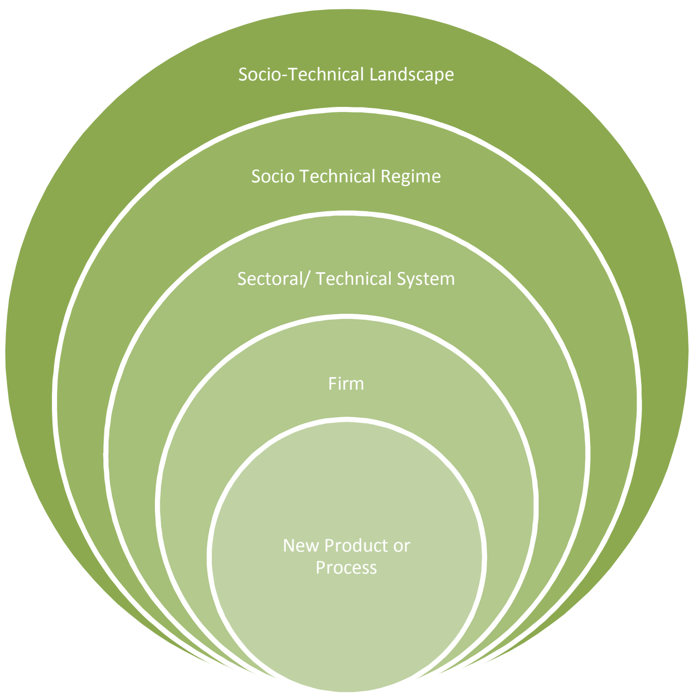


Figure 6: Innovation within contextual spheres

This diagram does not include the 'national systems' sphere since innovation, (irrespective of the clear and obvious geo-political, cultural and legal influences that the nation state exerts upon an innovation system) *may* cross national boundaries at almost all scales of analysis including both the firm and indeed for the innovation itself, depending upon the complexity of the innovation.

Hekkert and Negor also make comparisons of differing innovation systems inclusive of national innovation systems as outlined in their different works: (Negro, 2007, Hekkert *et al.*, 2007). Hekkert's comparison is shown in the below Figure 7.

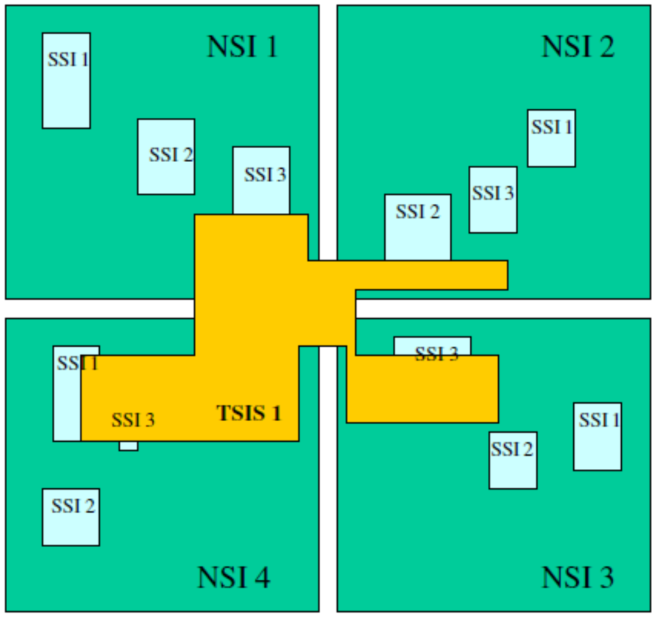


Figure 7: Hekkert's Boundary relations between National, Sectoral, and Technology Specific Innovation Systems (Hekkert *et al.*, 2007)

2.3.4 Theory of Energy and Renewable Energy Systems

Theories regarding the optimum way to support renewable energy have come out of some of the unique characteristics of renewable energy markets that are not present within 'normal' industrial economics. Firstly, it is evident that energy markets are (as Hughes would describe them) large technological systems of a utility scale (Mayntz and Hughes, 1988) that therefore have characteristics such as high levels of capital investment and many decades of investment legacy.

Since the structure of electricity markets includes a wide variety of non-standard arrangement and requirements (such as natural monopolies, real time demand/supply properties and strong non-economic dimensions such as carbon intensity of generation), many academics have studied some of the different ways not only that the markets work (which in the UK is described further within chapter 3, Background Review of the Sector) but how we can guide the market towards desirable outcomes such as energy security, reliability, sustainability and affordability.

With such a heterogeneous set of requirements that must be fulfilled, renewable energy support policies must take into account many aspects of the wider system in which they operate. Specific theories of 'what makes successful renewable energy policy' vary however and are themselves interlinked with varying theories of innovation, policy, sociology and our understanding of both the physical resources as well as the engineering that can extract energy from it.

Many of the other academics mentioned within this literature review have also done extensive work specifically on energy and renewable energy systems (Bergek, Foxon, Geels *et al.*) however the below theories are broken down into two rough categories that make them different from other approaches; those that are analytical case studies and those that make a holistic review of the energy system. Although not wholly justifiable (since almost all holistic assessments use empirical case studies for justification and of those case study centred approaches, there is usually a theoretical facet to analysis), the divisions below are thematically more coherent in their level of generalised conclusion and therefore applicability (i.e. case studies try to assess how something has historically happened from which similar future failings can be avoided and successes realised where-as the holistic approaches try to identify how the current system is operating and where failings and successes can be specifically identified).

2.3.4a Energy Systems Theory

Mitchell describes the Regulatory State Paradigm (RSP) (or the 'Band of Iron') (Mitchell, 2008). This is the system of supported and regulated competition (through Ofgem) that perceives market interference (i.e. the electricity market) as a bad thing, and the invisible hand of the free market (and price signals within the market) as being the best driver of innovation and a blanket belief that all innovation activity is 'good'. Mitchell argues that this is not the best (or cheapest) way to transition to a low carbon society. She suggests a sustainable energy system based on innovation being steered in a desirable direction for society rather than in a blue sky, 'cheapest option' way would lead to both an increase in diversity of both technology and actors within the market, (i.e. governments should 'fill the innovation shelf' rather than simply picking what the market brings onto it). To achieve this, the existing paradigm would need to be dismantled (i.e. Ofgem and the whole way in which the energy market operates) and a new one that both picks a technological trajectory, (i.e. decides where the system is planning to go) and reduces risk for all entrepreneurial actors within it (through less competitive, nurtured approaches to innovation) should be installed.

This idea of steering innovation within the energy market is not unique; Lund argues that a cost risk adverse subsidising of innovation (from a public sector perspective) through market pull mechanisms (such as FiTs and Green Certificates) produces lower deployment outcomes. By contrast, a 'catalysing' approach (technology push) in which products are pushed into commercial viability through targeted business development support and contracted outputs (for example) would result in faster commercialisation of preferred technology (Lund, 2006).

Hass *et al.* have conducted a broad-ranging analysis on historical energy consumption within society based on an assessment of an 'energy service' approach (looking at the outputs, (such as heating/cooling, lighting etc) rather than the energy itself. A model of 'impact factors' is created from which he concludes that an increase in energy efficiency itself commonly increases the amount of demand required (i.e. what is called the 'take-back' or 'rebound' effect). His conclusion is that we should rethink our relationship with energy to an energy service perspective; increasing energy conversion efficiency itself and provide the correct pricing and policy incentives to mitigate against 'take-back' effects when energy consumption increases (Haas *et al.*, 2008).

Mallon and Hass, among other things, discuss (based on case studies) supporting policy options that they suggest are key features for successful renewable energy policies. Hass *et al.* argues that the focus of support for policy makers must always be to trigger investment in new capacity while maintaining, upgrading and improving existing capacity through; sufficient price levels for renewable energy sources of electricity, long-term stability of support (such as 10 year grandfathering), fair and easy access to the grid for all generators and clear building codes for project developers (Haas *et al.*, 2004).

2.3.4b Renewable Energy Case Studies

As with other energy systems theory text, there are a multitude of academics who have built upon case studies of renewable energy within a specific country or region focussing on a particular technology to highlight particular policy failings or successes and draw generalising conclusions for what may work in future policy scenarios within similar contexts. Examples of this come from industries such as the (predominantly Danish) wind turbine, (Karnøe, 1990, Johnson and Jacobsson, 1998, Harborne and Hendry, 2009) solar, (Shum and Watanabe, 2009) and biomass industry (Negro, 2007) as well as a wealth of nationally focused policy papers that focus on the mechanisms as well as historical processes of change and policy framework rather than on any specific technology (Connor, 2003, Mitchell and Connor, 2004, Lund, 2006, Foxon and Pearson, 2007, Watson, 2008, Woodman and Mitchell, 2011).

There have also been several academic papers focussing specifically on the emergence of the UKs marine energy sector as a technology which (due to the obviously relevant nature of this thesis) are discussed in greater detail below:

Jeffrey has conducted stakeholder interviews to identify tacit knowledge (of problems and barriers) within the sector and convert this into codified, explicit information (Jeffrey, 2007). From the results of interviewing 22 stakeholders, he identified that a lack of physical validation on wave resource modelling, electrical grid and economic appraisal was present. He also identified a lack of knowledge regarding both the environmental effects of wave energy as well as an overall understanding of the wave (and tidal) resource was present. Broadly, he found that offshore (rather than nearshore) was the most favourable future technology, that there was disparity within the industry between complex, (higher output) devises and simplified (survivable) ones. Finally, he found that maintenance requirements were a concern for many (Jeffrey, 2007). Winskel, (based at the same university) translated work undertaken on a UKERC Sustainable Technology Programme into a marine energy innovation system study (Winskel *et al.*, 2006). Drawing on other sectors' historical emergence, (such as the wind industry) he identifies differentiating points about the UK marine energy sector such as Scotland's obvious prominence as a devolved country, limited linkages between a few leading developer forms, component suppliers and universities, and a general need for higher innovative network integration within the sector. Other, less formal measures such as; 'failure tolerance' and design diversity were also identified. Winskel also reflects on some of the innovation systems literature highlighting the (false) pretence that 'interactive learning' is simply an 'everybody wins' scenario which clearly ignores conflicts of self interest such as IP and competitiveness which are strong drivers within the marine energy sector (Winskel *et al.*, 2006).

Dalton, based at University College Cork has also written specifically on non-technical barriers to wave energy development specifically within Ireland (Dalton *et al.*, 2009). He classifies barriers as regulatory, logistical and financial. Much of his work is positive (in that it suggest simply what is occurring rather than giving policy suggestions) however he identifies that test centres should provide; EIA waivers, free cable connection, free data collection and adjacent service facilities. For regulatory policy; specific targets should direct policy, certainty in remuneration and revenue for projects, grants and support as well as tax concessions, simplified planning and licensing and a supportive grid connectivity network should all be in place to ensure deployment (Dalton *et al.*, 2009). In further work Dalton specifically assesses Ireland in terms of innovation, manufacturing and deployment (with comparison to other nations RE policies). He concludes that Ireland has fostered a positive deployment strategy historically (although not so successful on manufacturing) however (building upon his earlier work) there are several key areas that should be improved upon including: the creation of a wind energy strategy group (to provide developer-user learning), an increase to R&D budgets, the development of wave developer specific grid codes and standards, the establishment of a 30% capital grant subsidy system and a 3-5% corporate tax reduction system for developers, a planning 'fast-track' mechanism, an increase of feed in tariff and finally (for overall legitimacy an confidence in policy) a stable government (Dalton and Ó Gallachóir, 2010).

Finally, within the South West UK there have been several publication (related to the Wave Hub site) that have focussed upon stakeholder perceptions and site development. Connor discusses the various conflicts and challenges with different environmental impact measurements as well as the obvious problems that these discrepancies can cause with local stakeholder groups (specifically the affect of deployment upon the surfing community in North Cornwall) (Connor, 2007). Stakeholder views are investigated further by West who identifies stakeholder consultation failures and successes within the Wave Hub experience, specifically failures at informing 'grass root' stakeholders. She also suggests that a pragmatic and cautious approach should be adopted when highlighting the potential benefits of the scheme as overly inflated expectations have the potential for strong stakeholder disillusionment and hostility (West *et al.*, 2009).

2.3.5 Other Innovation Literature:

2.3.5a The Triple Helix of Innovation: Academia, Industry and Government

The triple helix theory of innovation comes from Etzkowitz (who coined the phrase) and Leydesdorff (Etzkowitz, 2001). In this book, Etzkowitz outlines what he argues is a fitting model of the current dynamic relationship between three specific actor groups, namely; academia, industry and government. In the latter part of the last century, Etzkowitz suggests that the traditional (and stand-alone) roles of universities as educators/researchers and businesses as economic value creators within society have blurred. Now, universities are building commercial acumen and products such as consultancy services, applied (industrially relevant) research projects, business incubators, patents, spin-out companies etc. Additionally, industry is now training its work force to a much higher standard (with generalised skills rather than just job-specific technical competence) as well as conducting more of the fundamental research that used to be the domain of universities. Governments role within this new paradigm, (so Etzkowitz argues) is to ensure that the applicability of research and relationship is focussed towards economically beneficial activity. Thus, there is constant and dynamic interaction within the triple helix model that is categorised by four dimensions (Etzkowitz, 2001):

- The internal collaboration and interaction within each of the helices, such as university-university joint research projects or strategic alliances among companies.
- The inter-helices relationships and effects upon each other, such as government changes to university funding or industrial development policy.
- The creation of wholly new interactive networks and bodies as a result of these inter-helices relations (such as mixed economic advisory, research or sector representation bodies).
- The (recursive) affects of the triple helix itself on wider society and social norms (such as the affects upon science or overall government policy from the helix).

2.3.5b Measures and Indicators

Measures and Indicators of innovation are clearly important aspects of any innovation analysis and metric indicators of innovation (and system functionality) are provided by many of the leading innovation academic within the sector (Carlsson and Stankiewicz, 1991, Carlsson *et al.*, 2002, Bergek *et al.*, 2005, Negro, 2007, Chang and Chen, 2003, Liu and White, 2001).

Perhaps the most recognised work on innovation metrics and data collection comes from the OECD who have produced two guidance manuals for methods of collection and interpretation of innovation data, (known as the Oslo Manual, now in its 3rd edition) and for the standardisation of surveys on research and experimental development, (known as the Frascati Manual) (OECD, 2002, OECD, 2005).

The Frascati manual was first published over 40 years ago however as our understanding of the causes of innovation (their indicators) has evolved, the manual has likewise evolved, more recently builds on (among others) the extensive research carried out by Freeman on the economics of innovation (Freeman, 1987, Freeman and Soete, 1997). The Frascati manual covers at a national level, not only methodologies for collecting innovation indicators but also provides a strong perspective on the interpretation and limitations that must be given to data. It is also the 'family head' (i.e. the overview book) in a suite of manuals aimed at assisting in the methodology of innovation research (OECD, 2002). As Freeman however points out, although one of the main theories within the manual involves the separation of the R&D function into the distinctly novel or routine categories, all metrics for R&D statistics within the manual are really a measure of the *professionalization* of R&D activity and fails to measure informal R&D activity (Freeman and Soete, 2007).

The other OECD book that has direct relevance to this research is the Guidelines for Collecting and Interpreting Innovation Data, otherwise known as the Oslo manual (OECD, 2005). This manual also comments on the weaknesses of assessing innovation with only codifiable information (such as patents and publications) suggesting that an understanding of the linkages between companies and some tacit knowledge of these interactions can give an understanding of the social, (or network) capital of an organisation, which may play a vital part of an enterprise's innovation strategies (OECD, 2005). In acquiring this information, (on network linkages) the Oslo manual suggests that it may be useful to collect important information on the characteristics of linkages such as the kind of knowledge transferred and the method of transfer.

2.3.5c Patents

Despite their known limitations, patents are one of the key indicators for innovative activity and are especially important in high technology research led industries. Inventors take on the risks associated with research and development, (R&D) under the premise that once a successful invention occurs, there work will be rewarded. The reward for this often comes in the form of a patent. Dosi outlines the following characteristics of specific patents, (Dosi *et al.*, 2006b) as follows:

- Patent Life: Simply defines the length of time a patent is applicable for.
- Amplitude, (breadth or diversity): This relates to the technological breadth of the patent in that it dictates the minimum number of components that must differ.
- Amplitude, (depth or improvement): This can be thought of as the minimum level of improvement to an existing patent that is required before it can be patented.
- Coarseness, (thick/thin): Relates to the patentable component resolution, whether the patent covers simply a component within a product or a whole product, (possibly consisting of other patented components.)

Historically, patents have allowed the inventor the right to prevent others from imitation: i.e. the right to excludability. Those that created the patent would have to be the one that fully commercialised the invention, (i.e. turn it into a successful innovation) or simply stop others from commercialising it themselves. In more recent decades however, the strengthening of patent laws and modern business practices have meant that the value of patents has taken a much wider understanding and the patents are used for: offensive strategies (to protect a monopoly), market strategies (to trade technologies), defensive strategies (to allow for cross-licensing and prevent exclusion), reputation strategies (to certify and signal competences), partnership strategies (through patent bargaining) and open strategies (to free technologies from ownership. (Julien, 2009)

2.3.6 Theory of Technological Change

2.3.6a Diffusion Theory and Selection Environment

Diffusion theory is in many ways, the bridging link of theory between much innovation theory, technological change and social network analysis. It looks at the way in which innovations diffuse among a set group of individuals (a community) through a distinctive dispersal and adoption pattern that can (to some extent) be predicted beforehand.

The most famous early study of diffusion (and the coining of the term 'diffusion' when applied to innovation diffusion) was that of Ryan and Gross (Ryan and Gross, 1943). This paper investigated the diffusion of hybrid corn among two Iowa communities over the period 1928 through to 1941 and sampled over 250 respondents. Ryan and Gross found that the process of diffusion for a superior form of hybrid corn depended heavily upon not only agri-business sales men, (who managed to persuade early adopters) but more so, on the informal networks of communication between farmers who had been using the corn and those that had not. In other words, it relied heavily upon what is today thought of as 'social capital' (Coleman, 1988). Although this research was not unique in looking at diffusion, it was a milestone for the formalisation of the theories and study of diffusion theory itself which was still a disperse discipline falling under the academic domains of rural sociology, marketing, education and anthropology among others at that time (Rogers, 2003).

It was not until Rogers' 1962 book, "Diffusion of Innovations" (Rogers, 2003) that diffusion theory was finally bought under one 'umbrella'. Bringing together the body of research done by various scholars within differing disciplines over the 40s and 50s on the process in which innovation and ideas spread throughout a community of adopters. In this book, he highlighted the commonality of findings that had been seen in previous works on diffusion such as the regular 'S-curve' of diffusion and the fact that early adopters (innovators) had higher socioeconomic status than later adopters (laggards) (Rogers, 2003).

Everett Rogers' found that the diffusion of almost all innovation within a culture of society tended to follow the 'S-curve' logistic function equation similar to Figure 8. This equation is:

$$y_t = b_0 + \frac{1}{1 + e^{-b_1 t}}$$

Where y is the proportion of adopters, b_0 the y intercept, t is time and b_1, the diffusion rate parameter (Valente, 2005).

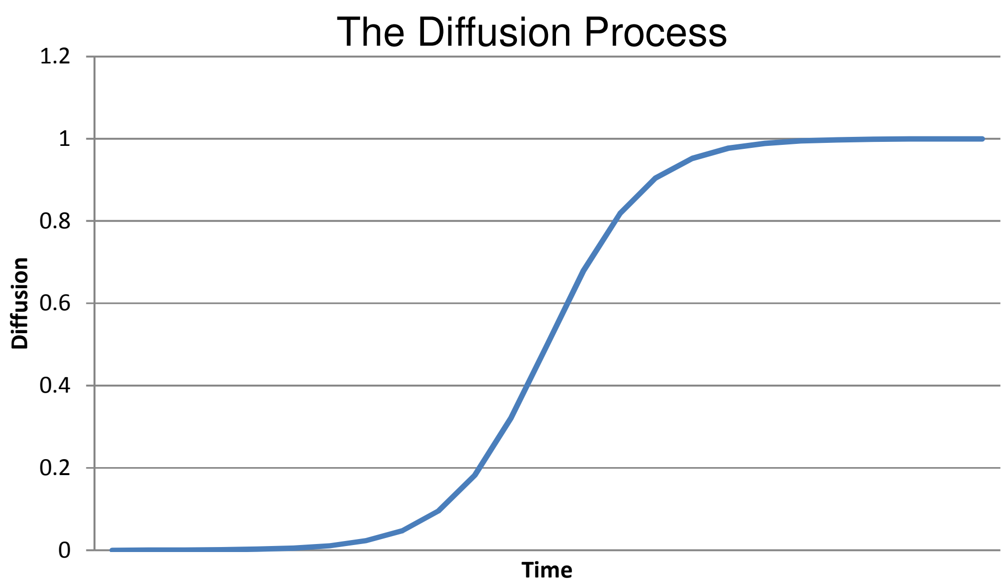


Figure 8: 'S-curve' of diffusion

He also highlights the four key elements that play a role in the diffusion of a new idea. These are: the innovation itself, communication channels (to and between actors), time and the social system, (population) in which it is diffusing.

Within renewable energy policy, diffusion theory has held a large level of interest for academic researchers since it can be used to model both the diffusion of renewable energy technologies adoption itself and also to help understand the social changes that drive many of the sustainable policies that decision makers use when thinking about adopting RE technology.

2.3.6b Technological Change

A notable paper on technology diffusion was Foxon et al.'s 2004 paper on UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures (Foxon *et al.*, 2005). Here, Foxon modelled the technology diffusion process through stages of technology maturity in which technologies pass. Rather than time, Foxon realised that market penetration of RE technology was reliant upon the level of technology maturity (and to some degree vice-versa since technology 'push' was required to achieve deployment that would in turn lead to increased learning).

Foxon's levels of technology maturity are described as:

- R&D: The basic principles of the technology are understood and no diffusion has occurred. There is still a great level of scope for radical levels of innovation.
- Demonstration: Attempts to design and build the technology are or have been made however the technology has not been proven to key early stage investors ('Innovators' (Rogers, 2003) or 'Movers' (Low and Abrahamson, 1997)).
- Pre-commercial: In which the technology has been proved however the economic scalability of the technology and its relationship to the existing status-quo is still uncertain. This period includes the 'valley of death' stage, in which a company is at high risk due to the high need for capital required for investment in plant and operations yet the low level of returns from the slow initial stages of diffusion.
- Supported commercial: This is the stage in which the technology is most likely to be driven by revenue based support, (market pull) and is effectively 'competing' within the status-quo arena, (similar to Geels' regime, (Geels, 2004)).
- Commercial: The final stage of maturity in which the technology is considered to be un-supported, (or in as much of a sense as all other technologies within the regime are un-supported) and able to compete 'on a level playing field'. The technology is thought to be fully mature at this point and only smaller incremental innovations are likely to occur.

Foxon *et al.*'s technology maturity curve can be seen in Figure 9 below.

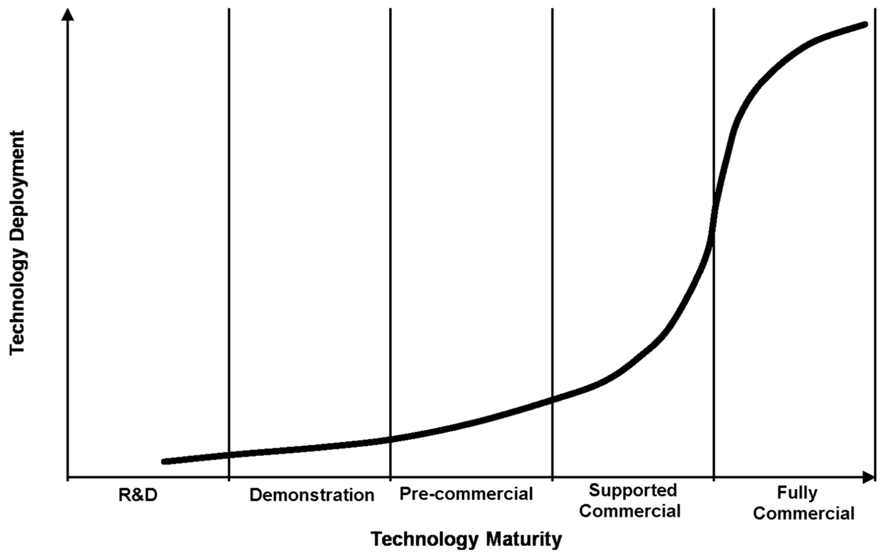


Figure 9: Foxon's Technology Maturity Curve (Foxon *et al.*, 2005)

In a similar vein to this, Dosi has worked heavily on technological paradigms that move along a trajectory through towards maturity (Dosi *et al.*, 1988). In his works, Dosi conceptualises the technological maturation of a sector as one in which the scope of the technological paradigm, (i.e. the level of both technological variation within the field and the heuristics of search) are initially wide however, as the technology matures, this search heuristic begins to focus, creating a narrowing of the overall paradigm. At a certain point of market pull, technology lock-in occurs and the process of change within the technology paradigm becomes, if not impossible, extremely difficult. This concept is outlined in Figure 10 below.

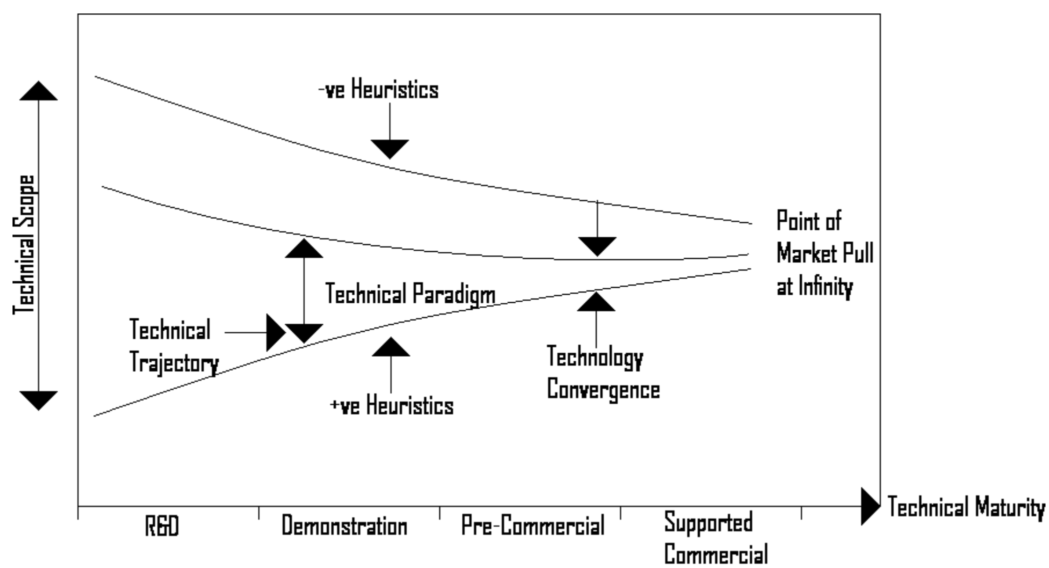


Figure 10: Conceptual model of Dosi's view on technological change

Geels also sources a third conceptual alternative to these from Gartner.com (Geels, 2005, Fenn and Linden, 2005). Although there is a similarity with technical time/maturity on the x axis, the

Technology Hype Cycle tries to reflect the visibility (*similar to the legitimacy)* of an emerging technology on the y axis as can be seen in below.

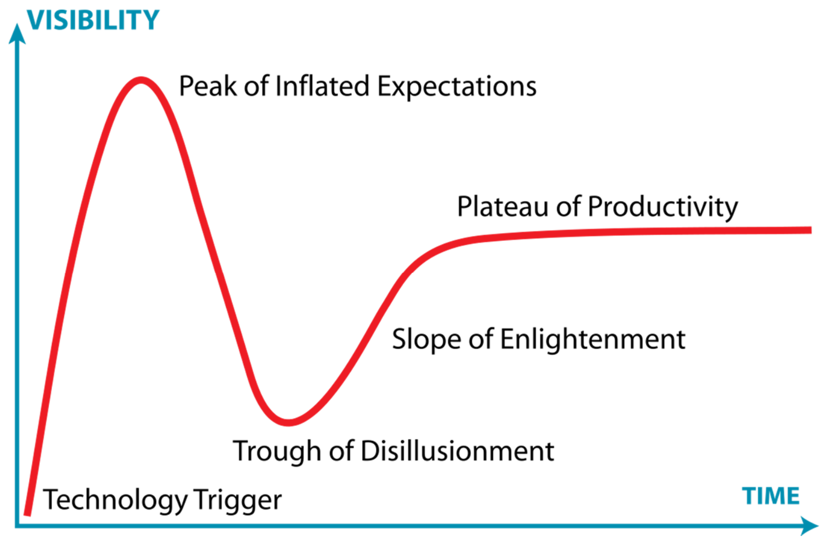


Figure 11: Technology Hype Cycle (Fenn and Linden, 2005)

Gartner, (A Stanford based IT consultancy) assert that all technology goes through the above (self explanatory) phases of maturity as they are being innovated upon and learned about. Eventually leading to a 'plateau' of productivity (this final stage may be far less than initial estimations of the technology however will at least be realistic in its appraisal).

2.3.6c Transition/Niche Management Theory

Within emerging systems of innovation, there is an acceptance that the rate of growth of the system may be slow due to high levels of uncertainty (and thus low legitimacy) in the overall technological trajectory and the associated high levels of financial risks for investment. This may be exacerbated in renewable energy systems where incumbent technologies (or the incumbent regime rather) needs overcoming and (in the case of fossil fuels) has a natural economic advantage (due to externalisation of carbon emission costs) while sustainable technologies rely heavily on the (often fickle) support of political will.

One of the current leading scholars in this field is Rob Raven. Working from Geels' multi-layered perspective of niches (See Socio-Technical Innovation Systems section, 2.3.3b above) as a model of transition management, Raven distinguishes the following aspects (Geels, 2004, Geels, 2005, Witkamp *et al.*, 2011, Raven *et al.*, 2010):

- On influence, landscapes (by definition) are external to any single actors influence and regimes are usually very stable, 'status-quo' fields that usually have strong inertia to change. Niches by contrast are usually under-developed and have little structure however the forming of institutional norms is still 'up-for grabs' (by prime movers and other early key stakeholders).

- Stakeholders will have different perspectives on what they believe to be different fields (niches/regimes and landscapes) therefore analysis is not ontological (i.e. the models of analysis are very much a relative construct of the researcher).
- Finally, successful transitions tended to occur through 'fruitful coupling' between all the different levels

When experimenting or applying instruments to encourage transition shifts, these fall into 3 broad notions: Deepening (activities that aim at learning as much as possible about the niche from an experiment or instrument), broadening (activities aimed at extending the application of an experiment or instrument to a different context within the niche), and scaling up, (activities aimed at bringing the experiment or instrument into a higher 'level' (i.e. the regime))(Raven *et al.*, 2010).

Separately, Raven identifies strategic niche management (SNM) as the focus of developing the niche layer of a system into a more developed stage (e.g. developing wave energy technology into the mainstream energy market). Here, Raven identifies three processes that tend to play an important aspect on niche success, these are (Raven *et al.*, 2010):

- The shaping of expectations which are positive when there is joint agreement within the niche over future expectations and these are borne out from tangible results (i.e. similar to the concepts of *search heuristic*s or *influence upon the direction of search* (Dosi, 1993, Bergek *et al.*, 2008a))
- The building of social networks coming from different field and disciplines, (supporting Burt's theory of structural holes discussed in the SNA within Innovation Studies section (2.4.4) below as well as Low and Abrahamson's development of successful industries (Burt, 1992, Low and Abrahamson, 1997)).
- A good, (broad yet flexible) learning process exists within the niche aligning the technical options with social ones.

2.3.7 Knowledge and Learning Theory

2.3.7a Types of Knowledge

Epistemology (the study of knowledge) has understandably received a great amount of research and branches into fields of philosophy, sociology, anthropology and many, many more disciplines. Within innovation theory and application however, its application often falls into two categories which relate to the characteristics of its presence; codified and tacit. Codified knowledge is knowledge that can be inscribed, recorded, patented and easily exchanged. This could be the blueprints for a wave energy converter or the recorded bathymetric data for a wave site. It is intrinsically transferable and can be (relatively) cheaply exchanged. It should be noted however that codifiable knowledge does not imply that the knowledge *has* been codified. There is often a misunderstanding between codifiable knowledge that has not been codified and tacit knowledge. Tacit knowledge by contrast is knowledge gained through experience and practice. This is not skill (as in physical ability to perform a feat) but rather, subtleties of knowledge that can only be gained though experience within the role. An example of this would be the difference between knowing how to drive a car and driving a specific old car, "the wheels pull a bit to the left and the windscreen wipers sometimes don't work" are tacit facts. A third element of knowledge to add to this is *competence*. This is the ability of firms to process codified knowledge in the correct fashion. Different levels of competence could cause two identical companies to respond differently to the same market knowledge such as a report. The competence of a company within knowledge transfer theory can be thought of in terms of three key company aspects; capacities to transfer knowledge, absorb knowledge and the motivation to teach knowledge (Easterby-Smith *et al.*, 2008).

The OECD Oslo manual defines various functionalities of knowledge beyond its tacit or codifiable nature including whether it is private or public, R&D based, specific (to an innovation) or generic and also whether it is embodied or disembodied within an innovation, (such as one would expect in a high technology system like a car or computer) (OECD, 2005)

Dosi outlines further subsidiary characteristics of knowledge as being: Non-exhaustive, non rival, (i.e. non-exclusive), hard to protect and cumulative. (Dosi *et al.*, 2006a)

2.3.7b Types of Learning

As well as the different aspects of knowledge, three specific ways of learning (or knowledge attainment) have been historically identified within evolutionary economics. These are:

- Learning by interaction: This is learning done by innovators through both feedback and increased product awareness such as companies learning from users about performance criteria issues or from suppliers about product potential improvement (Dosi *et al.*, 2002).
- Learning by using: This relates to learning done simply through the daily use of an innovation which enables the user. (Rosenberg, 1982).
- Learning by doing: This is the process of learning by making of the product in which understanding of the specifications, applications and limitations of the innovation may be refined. (Arrow, 1962, Rosenberg, 1982)

Other methods of learning are also highlighted that have been less widely focussed upon in academic literature. These include two forms of searching which Lundvall classifies as “learning by exploring” (which relates to what he describes as the less commercially orientated research activities of universities or public research bodies) and classical “learning by searching” which is a fairly overarching term that relating to the overall search heuristics of economic activity within a firm or sector (Lundvall, 1992). One other form of learning which also comes from an R&D perspective but unlike Lundvall’s distinctions has a company-scale dimension to it is “learning by trying” which Fleck identifies as a result of his case study within the Computer Aided Production Management sector. Learning by trying is the construction (by trial and error) of new and viable configurations of innovations, (also informally referred to as; “learning by ‘struggling to get it to work’”)(Fleck, 1994). This is in many ways a more ‘refined’ form of learning by doing or learning by searching Fleck argues that it has implications for the methodology that can be used to stimulate innovation activity.

2.3.7c Learning and Experience Curves

Learning and experience curves are ways of analysing the level of reductions in production cost that one would expect with and increased level of production (given the various factors that contribute to an economics of scales such as learning by doing etc). A learning curve simply measures the decrease in cost (or increase in performance) in relation to one particular input, (for example labour). An experience curve on the other hand, measures the performance relative to all the external inputs to the process (i.e. reductions in marketing, volume purchasing, improved manufacturing techniques etc.) and is often used within policy documents when assessing the expected overall cost reduction of increased deployment within renewable energy technologies (Wene, 2008). The generalised formula for the calculation of an experience curve is that a doubling of production produces a consistent percentage level of cost reduction, (for example between 10%-15%) as is shown in Equation 1 below.

$$P = A_O \times X^E$$

Equation 1: General Formula for an experience curve(Wene, 2008).

Where: P= the cumulative average cost or time per unit, A_O= cost or time required to produce the first unit, X= the cumulative number of units produced and E= the slope function when plotted on log/log paper, or the log of the learning rate, (e.g. 0.8 for an 80% cost at doubling of production) divided by the log of 2 (log(lr)/log(2)).

2.3.7d Knowledge Spillovers

Knowledge spillover is a form of positive externality for an organisation where knowledge is captured from closely proximate (either physically or on a knowledge bases) organisations. This can come in the form of direct employment of skills/labour from an adjacent industry, through informal communications or linkages and through more formal knowledge exchange mechanisms such as training/collaborating. Two opposing thoughts on knowledge spillover come from Jacobs and Marshall (Marshall, 1891, Jacobs, 1969). Jacobs suggests that externalities, (known as *Jacobian externalities*) are broadly understood to mean: "Inter-industrial knowledge spillovers" occurring in economically diverse cities as a result of the interaction of individuals possessing different backgrounds, effectively suggesting that diversity of actors (specifically within a city in her research but more generally applicable to any geographic area) is a strong motivator of innovative activity (Desrochers and Sautet, 2008). Marshall by contrast developed the idea that spillovers come from close proximity of similar-type actors (Marshall, 1891). This theory was was later refined further into to include Arrows and Romer in the Marshall-Arrow-Romer (MAR) model which suggests two types of spillover, internal (focussing on intra-company spillovers that occurs through discussion of employees internal to an organisation) and external (that results from interactions within a city) as part of a cluster benefit (Glaeser *et al.*, 1992). Glaeser *et al.*, who coined the term MAR spillovers, actually found through his research that Jacobian spillovers (through diversification) were more evident however argued that within emerging and growth industries, MAR spillovers are more important (Glaeser *et al.*, 1992). More recently and by contrast to this however, Beaudry *et al.* assessed much of the prevailing literature on the argument of spillovers finding that (although varying for different technology complexities and market stages) both spillovers are generally present and positive however Jacobian spillovers should be promoted within high technology markets whereas MAR spillovers lead to higher innovative output within lower technology and more *mature* markets instead (Beaudry and Schiffauerova, 2009). Beaudry *et al.* does however also suggest that there are many non-negligible negative effects of MAR spillovers which may in fact hinder economic growth (such as a lack of flexibility to adjust to exogenous changes and a higher likelihood of experiencing lock-in or bounded rationality within the sector). Ultimately, theories supporting both aspects of spillover are still strongly present and further research is clearly required as to which form is most likely to increase innovative capacity within a region/sector.

2.3.7e Entrepreneurial Theory

Entrepreneurial theory is a large academic field in its own right and one that began with the famous social scientist Joseph Shumpeter. Although also famous for his later work on business cycles and the theory of 'creative destruction', Shumpeter first developed the idea of an entrepreneur. Entrepreneur's are agents of change and fulfil the 'entrepreneurial function' that distinguishes an invention from an innovation, in that their attempts to commercialise it go against the incumbency and social inertia of the status-quo as well as their own internal inertia (Schumpeter, 1934). Initially, Schumpeter identified individuals as entrepreneurs (what is often referred to as Mark 1 Schumpeter) however in his later work in the US, he developed a superseding theory that large organisations were often the primary agents of entrepreneurial activity due to the amount of time and capital that they could devote to the innovation process (now called Mark 2 Schumpeter) (Schumpeter, 1947).

In this later work he describes the creative response of an economy, industry or firm, (as opposed to the routine reactive response) as having three dimensions; unpredictability ex-ante of the response, a shaping effect upon the long term outcome of the respondent and a factor of the qualities and decisions made by those within the economy/industry/firm. This last point is what makes the study of industrial creative response synonymous with entrepreneurial activity (Schumpeter, 1947).

He later goes on to argue that the entrepreneurial characteristic can be classified as the doing of something new or the doing of something that has already been done in a new way (described as process innovation). Entrepreneurship should however be made distinct from other functions within an organisation such as the manager, 'capitalist function' (i.e. the provider of resource to allow the entrepreneurial behaviour) or the inventor, who produces ideas but, unlike the entrepreneur does not 'bring them to market'.

Although there are many academic theories on entrepreneurship, much work looks at the role and context of entrepreneurs within context of industry or industrial maturity. An example of this is the work of Low and Abrahamson who argue that three distinct types of entrepreneurs emerge through the three stages of industrial maturity they identify as; emerging, (when the market is still extremely immature), growing and mature, (the last and most refined state of industry) similar to those phases outlined by Foxon, Dosi and others above. The three entrepreneurial forms are; 'Movers', 'Bandwagons' and 'Clones' (Low and Abrahamson, 1997). Movers suit emerging industries and tend to be socially motivated, high risk takers who exploit links between previously un-connected subgroups (supporting Burt's theories of structural holes outlined in section 2.4.4 of this chapter (Burt, 1992)). 'Bandwagons' are suited to the growth phase of the market and have large, diverse networks with weak ties. Their key challenge is to prosper amidst the rapid growth of the sector, bringing activities in house, seizing the window of economic opportunity to secure dominance through the development of standards and internal institutional barriers to new entrants. Finally, in mature markets, 'Clones' are entrepreneurs within an established market who rely on assessing different aspects of the value chain to increase margins while imitating 'best practice' models within the industry while incrementally innovating (Low and Abrahamson, 1997).

2.4 Social Network Analysis Theory

2.4.1 Introduction to Social Network Analysis

Social Network Analysis, (SNA) is the amalgamated science of graph theory with an understanding around the interaction of agents as social actors within a wider network or system. Network analysis has historically been used since the mid 1930s in disciplines as diverse as epidemiology, policy, biology and any other field in which the meso scale of interactions between different actors is important to an understanding of the science (Christopoulos, 2009, Wasserman *et al.*, 2005).

Network analysis gained considerable attending at the end of the 60s due to a relatively small article by Stanley Milgram in the trade magazine, Psychology Today entitled "The Small-World Problem" (Milgram, 1967). Interest in the field however began to grow much more rapidly in 1990s, with the advent of both high powered computing availability, the release of specialist software packages (such as Ucinet) and a growing acknowledgement that networks were vital in understanding fields such as the spread of AIDS (through sexual networks) and in more recent years, in understanding the operation of terrorist networks, (West Point academy, NY now has a prominent SNA department).

Carlsson states that, "Networks are an intermediate form of organisation between hierarchies of internal organisations, (such as firms) and markets. Their essential function is the exchange of information" (Carlsson and Stankiewicz, 1991). As such it should seem natural that SNA be used as a tool for analysis within business and economic studies, the theory of networks of actors and their interactions is indeed central to most innovation and business systems analysis.

2.4.2 Fundamentals of Graph Theory and SNA

Networks are made up of two fundamental elements, actors, (or nodes) and linkages between them, which are referred to as ties, (or edges). Actors can represent many things: discreet individuals, corporations or collective social units for example (Wasserman and Faust, 1994). They can also represent locations, (such as cities, meetings or countries) inanimate objects (such as patents or computers) or even a combination of more than one of these types of actor, (such cases are known as two-mode networks.

The ties between these nodes could represent many things also, from the flow of a product, service or knowledge, to social interactions, relationships, movements, physical connections or even the non-enacted resource of the relationship (Christopoulos, 2009). These ties may have differing qualities also. They may be symmetrical or asymmetrical in that they may be one directional or reciprocated. A tie may be positive, negative or simply not present. If one were to ask who a person likes or dislikes in a social group this would constitute what is referred to as a 'weighted tie' (i.e. with +ve, -ve or 0 options). Other types of quality include whether the tie is binary, ranked or valued.

Analysis of all relationships that are connected to one node are called an 'ego network' analysis and the surrounding periphery nodes are referred to as 'alters'. Between an ego-network analysis and the whole network, there are varying 'composition' levels of analysis in which small groups, cliques and clusters can be analysed (Hanneman and Riddle, 2005). An analysis between the relationships of two actors is at the most simplistic level, referred to as a dyadic relationship or analysis (whether there is in fact a relationship present or not) and looks solely at the relationship between these two actors. Between three actors, is a triadic relationship and so on (although the level of insight that one can gain from relationships sub-sets of four and above becomes limited). Various theories are suggested about both dyadic and triadic analysis. For example, in sociological dyadic relationships, Homans says that; "the more frequently persons interacts with one another, the stronger their sentiment of friendship for one another are apt to be" (Homans, 1951). Granovetter also argues based on an extensive review of other work that with triadic relations that the stronger a tie between two actors, the larger the probability that individuals within either of their networks will be tied to both of them (Granovetter, 1973).

As the presence or not of relationships between different actors can be categorised to some extent, so can the structure and number of relationships within a sub group of, or indeed the network as a whole. This can tell us something about the type of group being analysed and opens up a wider field of terminology and metrics that are discussed below:

2.4.2a Centrality

Centrality is a key attribute within SNA analysis that is used to determine how central, (and in most cases therefore, how important, powerful or influential) a particular node is with respect to the overall group. There are several key measures that can be used for centrality depending upon the analysis however the basic three main measures of centrality were outlined by Freeman in his 1978 paper: Centrality in social networks conceptual clarification (Freeman, 1978) and are described from this paper and others below (Christopoulos, 2009, Hanneman and Riddle, 2005, Carrington *et al.*, 2005, Ruhnau, 2000):

- **Degree Centrality:** This is a measure of the number of in-ties that a node has within a given network and relates simply to a measure of how many direct relationships that the node has connected to it. It can be normalised against either the total number of available ties, (i.e. n-1 since the node cannot connect to itself) or to the node with the highest level of degree centrality within the network, (i.e. with the most well connected node having a value of 1). If The node represents N_D then the equation for degree centrality is given in :

$$C_D(pk) = \sum_{i=1}^{n} a(pi, pk)$$

Equation 2: Degree centrality (for Pk)

Where $a(pi, pk) = 1$ only if pi and pk are connected by a line, (otherwise they are equal to 0).

For weighted (valued) networks, weighted degree centrality (also called node strength) can be defined as the sum of the values of all ties connected to the node as shown in Equation 3 (Barrat *et al.*, 2004).

$$C_D^W(pk) = \sum_{i}^{n} w(pi, pk)$$

Equation 3: Weighted Degree Centrality or Node Strength (for Pk)

Where *w* refers to the weight of the tie.

For valued asymmetric ties where there is direction to the network, 'in' and 'out' degree centrality can be used. Within asymmetric social networks, if an actor receives many ties, they are referred to as 'prominent'. If they give many ties, they are said to be 'influential' (Hanneman and Riddle, 2005).

- **Betweenness Centrality:** This measure quantifies how central an actor is based upon how much brokerage of information or goods the node has in relation to all others. In other words, how many nodes 'geodesic distances' it lies upon within the network. The geodesic distance between two nodes, is the *shortest* number of ties possible between the two. Therefore, if a node sits within a central point, it will tend to fall within the geodesic path of many of the more peripheral nodes. To illustrate this, the below diagram shows a network of five points in a 'star' connection in which node J (p_J) has the central role. From a simple degree centrality it can be seen that p_J has a centrality of 4 ($p_H > p_J$, $p_I > p_J$, $p_L > p_J$, $p_K > p_J = 4$)

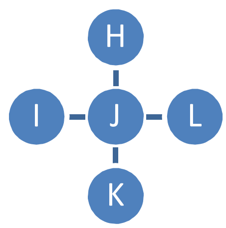


Figure 12: Betweenness Centrality Example

If we were to calculate the betweenness centrality measure C_B however it would be 6 since p_J falls between the geodesic distances of all the other combinations:

$p_H > p_J > p_I$ (1)
$p_H > p_J > p_K$ (2)
$p_H > p_J > p_L$ (3)
$p_I > p_J > p_K$ (4)
$p_I > p_J > p_L$ (5)
$p_K > p_J > p_L$ (6)

(Since p_J's own connections cannot be included, 6 is the maximum level of centrality possible for a 5 node network).

This measure however gets a little more complicated when there is more than one potential geodesic line between nodes. In this case, assuming that the number of geodesics linking p_H with p_I in which p_J sits is denoted by g_{HI} (p_J) then the probability of p_J falling upon a geodesic between p_H and p_I is given in Equation 4:

$$b_{HI}(p_J) = \frac{g_{HI}(p_J)}{g_{HI}}$$

Equation 4: Betweeness probability of p_J

So for example, let us say there were three nodes with a tie to both p_H and p_I, (of which p_J was one) then for their relationship $b_{HI}(p_J)$ = 0.33 (i.e. 1/3).

As a result, for a complete network level of centrality, these probabilities of geodesic betweenness need to be summated giving an overall level of centrality (that can then be normalised again if desired) but would look like this:

$$C_B(p_J) = \sum_{H<}^{n} \sum_{I}^{n} b_{HI}(p_J)$$

Equation 5: Betweenness centrality measure (for p_J)

This is where p_H is not p_I or p_J. (Freeman, 1978)

Freeman expanded upon this measure to include weighted networks in which (given that the ties were not binary) the maximum 'capacity' between two nodes cannot exceed the sum of the lowest edge weightings (Freeman *et al.*, 1991). For example, in Figure 13 below the maximum capacity between node B and A would be 4 (3 from B>A and 1 from B>C>A since the maximum capacity of B>C is 1). The betweenness centrality for A would be the sum of the flows going *through* A from any other node going to all other nodes as ratio of that total flow.

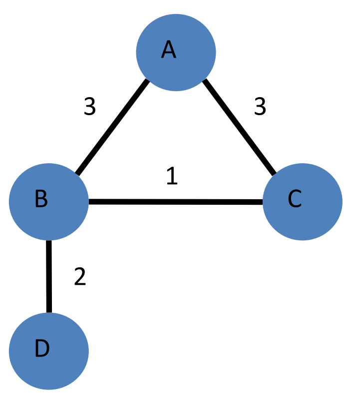


Figure 13: Weighted Network

So let us exemplify this by calculating the betweenness for node A in the Figure 13 network.

For B:

From B-C

B>C (1) & B>A>C (3) therefore A provides 3 from a total of 4 between B-C, = ¾

From B-D

B>D (2) therefore A provides 0 from a total of 2 links between B-D, = 0/2 = 0

So the total sum of B's betweenness to A is ¾ + 0 = ¾

For C:

From C-B

C>B (1) & C>A>B (3) therefore A provides 3 from a total of 4 links between C-B, = ¾

From C-D

C>B>D (1) & C>A>B>D (1) (Since the B>D edge has a maximum capacity of 2), therefore A provides 1 from a total of 2 links between C-D, = ½

So the total sum of C's betweenness to A is ¾ + ½ = 1¼

For D:

From D-B

D>B (2) therefore A provides 0 from a total of 2 links between D-B, = 0/2 = 0

From D-C

D>B>C (1) & D>B>A>C (1) (Since the D>B edge has a maximum capacity of 2), therefore A provides 1 from a total of 2 links between D-C, = ½

So the total sum of D's betweenness to A is 0+ ½ = ½

Summating these, A has a total betweenness of: ¾ + 1¼ + ½ = 2½ or 2.5

This value can then be normalised against the maximum level of betweenness that any node in the network can provide (i.e. directly contributing to every node except the origin node and the node whose centrality is being calculated). In the above example, node A would have a normalised betweenness of 2.5/6 (i.e.2.5 for the raw betweenness score and 6 for the maximum raw betweenness score available) = 0.416 or 41.6%.

- **Closeness Centrality:** This final measure of centrality is somewhat simpler than the concept of betweenness centrality but still uses the geodesics between nodes. In this version, centrality is a measure of how easy it is for a node to communicate with all other nodes within the network and is worked out by taking the sum of the geodesic distances between the focal node in question (or 'ego') and all other nodes within the network. This figure will give a measure of *farness* which is how remote the node is from all others. The reciprocal of this is therefore the *closeness* and gives an insight into the distance to which all actors lie from the ego node. This can be represented in Equation 6:

$$C_c(p_k) = \frac{1}{\sum_{i=1}^{n} d(p_i, p_k)}$$

Equation 6: Closeness centrality equation (for p_k)

Where p_k= the ego node, and $d(p_i, p_k)$= the geodesic distance between nodes p_i and p_k. One of the problems with this measure is that it does not take into account disjointed networks and can thus only give an impression of the largest cohesive clique within a network (see Harmonic Closeness below for solutions to this problem).

In weighted ties networks, the inverse of the weighting is taken (known as the 'cost') and the summing of least costs to every other node in the network are then taken to calculate the farness (Dijkstra, 1959). This is then reciprocated to give a weighted closeness centrality.

Building upon these existing measure, two final measures of singular node centrality are introduced, these are: Harmonic Centrality and Eigenvector Centrality (Opsahl, 2010, Hanneman and Riddle, 2005, Bonacich, 1987).

- **Harmonic Closeness Centrality:** This measure of centrality is very similar to the Closeness centrality measure outlined above. The main problem with closeness centrality however is that when the network is disjointed, (i.e. not all nodes have a connection to other nodes) the level of *farness* for the node instantly becomes infinity. The level of centrality is therefore 0. One measure that can be used to overcome this is to take the reciprocal of the individual farness measures for each geodesic and then sum these afterwards as can be seen in Equation 7:

$$C_{hc}(p_k) = \sum_{i=1}^{n} \frac{1}{d(p_i, p_k)}$$

Equation 7: Harmonic closeness (for p_k)

Again, where p_k= the ego node, and $d(p_i, p_k)$= the geodesic distance between nodes p_i and p_k.

In this fashion, all infinite geodesics (i.e. unconnected ties) add a value of 0 to the overall measure whereas those that are connected (regardless of how many spaces away they are) add a value that decreases as the path length increases. Since the level of harmonic closeness is always going to be higher for larger networks, the values of harmonic closeness can be normalised (for either singular or multidimensional networks of the same group) against the highest theoretical value of harmonic closeness available within the network. Note that this 'norming' is not done relative to the highest centrality measure obtained in this procedure but it usually done relative to the network theoretical maximum as a whole.

- **Eigenvector Centrality:** Eigenvector centrality is a measure of centrality that tries to take the level of centrality that ones immediate and connected neighbours (alters) have into account when calculating a level of centrality for the ego node. Bonachich developed a technique (now known as Bonacich's eigenvector centrality measure) in which he defines the centrality (*c*) of *i* as; c_i which is expressed in Equation 8:

$$\lambda c_i = \sum_j R_{ij} c_j,$$

Equation 8: Eigenvector centrality (for *i*)

where: λ is a constant (required to ensure that the equation has non-zero solutions) and R is the adjacency matrix. If the matrix is rewritten this can be presented as:

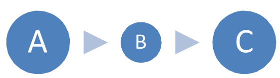
$$\lambda e = Re,$$

It should be noted that eigenvector centrality is a measure of centrality that only works with symmetric ties. For an undirected equivalent measure, Bonacich suggests an alternative approach that are outlined in: Eigenvector-like measures of centrality for asymmetric relations, (Bonacich and Lloyd,

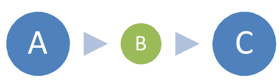
2001) which is the method used by the software package Ucinet for a directed tie approach to eigenvector centrality.

2.4.2b Brokerage

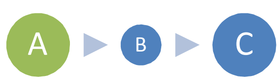
Brokerage is the notion that power can exist through the ability to act as a broker from one node to another, (similar to 'betweenness centrality'). The most prominent work on definitions of brokerage was done by Gould who defined brokerage as "a process by which intermediary actors facilitate transactions between one actor lacking access to or trust in one another" (Gould and Fernandez, 1989a). Gould created a simple five form taxonomy of natural brokerage types which covered all possible forms of brokerage between three nodes from different types of groups and are shown below:



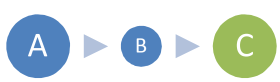
B= Coordinator. A,B & C are from the same group (for example, the coordinator within an academic network).



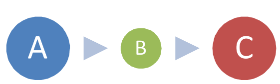
B= Itinerant Broker. A & C are from the same group (for example, an industry trade organisation).



B= Gatekeeper. B & C are from the same group (for example, a public sector planning agency (who would disseminate applications to other



B= Representative. A & B are from the same group (for example, a final stage sub-component manufacturer).



B= Liaison. Neither A, B nor C are from the same group (for example,

Figure 14: Gould's Broker Taxonomy (Gould and Fernandez, 1989a)

Brokerage occurs when A>B and B>C but $A \not> C$. Conducting a brokerage analysis of a network can assist in assessing what type of relationships are forming and how much interaction is occurring between different sub group types. This could for example, show the levels of interaction between universities and companies within a network from which comparison could be made between different networks (e.g. Scotland and England or marine and wave). This measure is not as useful however as a group centrality measure for cross-group communications.

2.4.2c Density

The density of a network is a simple measure of how cohesive a network is and is calculated (within a binary symmetric networks) as a percentage of the maximum possible level of ties. Thus, it is simply measured by then number of ties in a network, divided by the number of possible pairs multiplied by 100. For directed or weighted ties, it is possible to have an ‘in’ and ‘out’ density or to normalise the results respectively.

2.4.2d Reciprocity

Reciprocity is a measure of the level to which having a tie with a node is likely result in a returning tie from them (in asymmetric networks). This is calculated by counting the number of reciprocated ties within a network and then dividing it with the number of overall ties within a network (regardless of reciprocity).

2.4.2e Sub-Group Analysis

There are various different measures for creating cohesive sub-groups from a matrix depending upon; a) the type of data set that is used (i.e. large sparse data sets may use less robust measures to find subgroups then small dense data sets), b) the number of sub-groups that are being looked for (i.e. it may be that the researcher is looking for a high number of small subgroups or a small number of large subgroups) and c) the process of matrix modification used to manipulate the data for analysis (i.e. most algorithms for subgroup analysis work on binary symmetrised data sets and it may be more appropriate to manipulate the data in different ways depending upon the nature of the overall graph and the meaning of the ties.

The main type of sub-graphs available are (Wasserman and Faust, 1994):

- **Cliques:** A simple clique is a sub group in which all member nodes are adjacent to one another (i.e. attached by an edge). Since this term can severely limit the number of cliques in many networks, n-cliques can be used instead. n-cliques are ones in which all nodes within a subgroup can be reached by a geodesic path length of n or less and such and the subgroup is at maximum saturation. Although n-cliques are used extensively, they have two problems in that subgroups diameters can be much wider than n (since non-member nodes can be on the geodesic distance between members) and that they can in fact be non-cohesive (i.e. not formed into one connected network) again, since non-member nodes can form the geodesic distances between sub-group members. These problems can be rectified using clans, clubs, k-plexes and k-cores.

- **Clans and Clubs:** Clans (or n-clans) can be calculated simply by taking a set of n-cliques and removing with a diameter greater than n, (e.g. the maximum diameter for a 2n clan would be 2) while a club (or n-club) is a the same as an n-clan but in which the geodesic distances within the subgroup cannot be more than n. Although similar sounding in concept, clubs effectively restricts groups to much 'tighter' (i.e. star/pendent or fully connected) relationships for 2n clubs) subgroups.
- **K-Plexes and K-Cores:** K-Plexes allow for subgroups that are less fully connected but usually more 'robust' (in that they are less susceptible to breaking up with the removal of a singular node). For a k-plex subgroup, all member nodes are allowed to be *unconnected* to a maximum of k members within the subgroup, (or in other words, must connect to the whole subgroup minus k members). K-Core subgroups are similar to k-plex ones but instead of specifying the number that allowed to be non-connected, the k specifies the minimum number of other nodes within the subgroup that the node must be connected to (effectively the opposite to k-plexes) (Seidman and Foster, 1978).

Although all these measures are usually analysed for binary, non-directed ties, dichotomisation of the data set can create an effective 'cut-off' point for analysis of valued data. With directed data, there are four forms of relationship which creates respective sub-classifications for the above subgroups and these are:

- Weakly n-connected: This is a path between two nodes in a subgroup that is connected irrespective of directionality, identical to a symmetrised data set with a maximum cut-off point, (e.g. a>b<c still connects a-c)
- Unilaterally n-connected: takes into account directionality but only assumes that one node need be connected to the other, (e.g. only a>b>c connects a-c).
- Strongly n-connected: Assumes that both nodes must be directionally related to each other but not necessarily through the same path, (e.g. if a>b>c and c>d>a then a-c but not without d being present).

- Recursively n-connected: finally, this connectivity is only present if the directed paths taken by each node is the same as the returning relationship, (e.g. the strongly connected path above would not count as an, a-c recursively connected relationship however if a<>b<>c then a-c).

All of these directed relationships can be applied to the above sub-group types so for example, to find recursively n-connected K-Plexes where the cut-off value c=5 within a weighted matrix, one would need to first dichotomise the data-set to 5≥ =1, then add the transpose of the matrix (so that all reciprocal ties = 2 and singular ties still equal 1), dichotomise the data-set again to 2≥ 1 then perform a k-plex analysis.

2.4.3 Other SNA Concepts

2.4.3a Homophily

Homophily is a term that relates to the level by which actors of the same type chose each other within a network. So for example, a wave energy sector with a high level of national homophily would be one in which actors within separate nations tended to choose others from their same country to interact with rather than international actors. Homophily measures of cohesion are defined by Krackhardt et al. who proposed the E-I Index as a measure of homophily (Krackhardt and Stern, 1988). In this measure, E-I varies from -1 to +1 with -1 equating to a high level of homophily and +1 equating to a high level of hetrophily, (the opposite of homophily). The equation for EI is given in Equation 9 below in which EL = the sum of all external linkages *between* groups (this may be the sum of all valued external linkages within a valued network) and IL = the sum of all *internal* linkages (again valued or binary) within groups of the network.

$$E - I = \frac{EL - IL}{EL + IL}$$

Equation 9: External/Internal Homophily measure (Krackhardt and Stern, 1988)

Krackhardt argues that a high level of homophily is a *negative* network attribute as, in times of organisational crisis, trust between intra-firm sub-groups (or subunits) is low if homophily is high and this in turn inhibits the organisation’s ability to adapt and problem solve. Although this conclusion cannot be translated directly into an inter-firm model without further justification, (some of which has been provided by Granovetter and his theory of the strength of weak ties below) it provides an interesting indicator as to the make-up of a network and between actor types.

Rogers also argues that homophily is a barrier to diffusion within innovation systems since it would mean that higher status, innovative actors would be more likely to mainly interact within one another and thus innovation would not 'trickle down' to others within the diffusion/innovation network (Rogers, 2003).

2.4.3b Clustering

Clustering is the level to which an individual's alters are connected to each other and is used in assessing the 'clumpiness' of a networks distribution. It is integral to theories such as 'small world' relationships between people (popularised by Milgram and Watts *et al.* among others (Milgram, 1967, Watts and Strogatz, 1998) as it gives a value of how clustered social groupings are allows analysts to assess what level a network of relations is uniformly distributed or grouped into tight social (or innovative) clumps.

The metric of clustering is clustering coefficient which, for individual actors can be defined as the average density of its direct neighbourhood network, (i.e. connected alters) excluding itself. It is therefore a measure of how well connected ones alters are. For a whole network, this measure is the ratio of the amount of alter connectivity relative to a saturated full level of alter connectivity. Mathematically therefore it can be defined as the summation of each individual actor's clustering coefficient divided by the summated maximum potential for each individual actor (Watts, 1999, Watts and Strogatz, 1998, Hanneman and Riddle, 2005).

2.4.4 SNA within Innovation Studies

SNA is based on several principles that are complimentary to an evolutionary economics perspective in that actors share interdependencies, and holds attributes such as their 'network horizon' (Anderson *et al.*, 1994) which, in evolutionary economics is equivalent to the theory of 'bounded rationality' (Nelson and Winter, 1982). More importantly however, as Coleman states: "The perception of economic actors as having goals independently arrived at and wholly self interested in maximising utility… flies in the face of empirical reality; persons' actions are shaped, redirected, constrained by the context; norms, interpersonal trust, social networks, and social organisation *(that are)* important in the functioning not only of the society but also of the economy" (Coleman, 1988).

Although the actual application of SNA within economic innovation studies is a fairly recently development, it has most commonly been applied to model diffusion theory, whereby nodes represent users and the ties are lines of innovation/product diffusion. Additionally, SNA is beginning to be explored in patent/citation analysis (Fleming *et al.*, 2007a, Fleming *et al.*, 2007b), intra-firm network analysis (Tsai, 2000, Tsai, 2001), 'entrepreneur network' analysis, (Burt, 1992, Shan *et al.*, 1994) and an ever expanding list of applications associated with innovation studies. To date, there have been no explicit attempts to introduce SNA as an applicable tool within systems of innovation of any kind.

Ties to partners with whom communication is frequent are often called "strong ties," while those that are more occasional are denoted as "weak ties" (Fagerberg *et al.*, 2005, Granovetter, 1973). Within the main applications of SNA to Innovation studies, there is a dominant perception that weak ties hamper complex knowledge flows that require strong ties to transfer (Hansen, 1999) and that densely clustered local networks are better for creating intangible elements such as 'social capital' which build trustworthiness, business norms and practices and informal information channels that allow for easier cross-communication (or lower transaction costs) (Granovetter, 1973, Walker *et al.*, 1997, Coleman, 1988). Complimenting this theory is the notion that within complex, (e.g. high tech) knowledge based industries, such as the marine renewable sector, the locus of innovation itself can be found in networks of learning (also known as *problem solving*, or *support* networks) rather than within individual firms (Powell *et al.*, 1996, OECD, 2005). Therefore, strong and cohesive networks of learning within a community are required to aid transmission of knowledge flows and bring innovation to fruition. Direct and indirect ties (i.e. through ones alters to their other ties) are both associated with higher complex knowledge generation, while structural holes (discussed below) have a negative effect on it (Ahuja, 2000).

While cohesive networks can be considered most desirable from a systemic innovation perspective, it must be remembered that there is a *transaction cost* associated with maintaining any relationship between actors. Transaction costs are the cost required to both build and maintain a strong relationship between actors be they in terms of man power, money or other resources (such as meeting rooms, transport etc.) As connectivity to cohesive local alters increases, *redundancy* affects start to emerge. Redundancy is a situation where an actor's (ego) direct relationships (alters) have connections to each other as well as ego (Borgatti, 1997). As such, the individual value of access to each of alter relationship's networks become less (since it is more likely that the ego actor already has connectivity to them). At some point in an entrepreneur's network expansion, the transaction cost of interaction becomes outweighed by the diminishment of network benefits obtained through ever increasing redundancy of contacts (Jonard, 2009).

From a systemic perspective then, a highly exploited level of system potential (i.e. a closed and dense network), would give optimum performance up to a point of network 'saturation' where diminishing returns of redundancy are outweighed by the transaction costs of the relationship. Network cohesion is therefore desirable within epistemic problem solving networks (such as university research) even though the 'network benefits' to individual nodes are homogenous/equal.

From an individual entrepreneurial perspective however, this may not be the best form of network. Structural bridging (being placed as the bridging node connecting two or more un-connected clusters of nodes) creates benefits individually from network brokerage (see brokerage metric above) or arbitration as well as from being able to synthesise knowledge unique to both networks for egos own problem solving. Additionally, network bridging allows actors to be more flexible against technology surprises (such as radical altering innovation) which may be unforeseeable within the local cluster (Jonard, 2009). This theory, (similar to that of Jacobian spillovers in that it values diversity of actors (Jacobs, 1969)) was first explored (albeit within social groups) by Granovetter who called it the 'strength of weak ties' (Granovetter, 1973).

Granovetter argued that bridging ties are better for finding (specifically scarce) resources or information than closer local ties since there is more likely to be a higher level of 'redundancy' within the local network and thus network inefficiencies (see dyadic and triadic relationships in the Fundamentals of Graph Theory section above, (2.4.2)). From a strategic point of view, he therefore surmised that it could produce better resource payoffs to have more ties with weaker links (i.e. those with lower levels of redundancy)(Granovetter, 1973). Although the underlying triadic premise of Granovetter's theory (that if A and B are strongly tied, there is a higher probability that their other ties will be mutually shared, therefore bridging ties must by definition be weak) does not hold directly true for non-social interactions (since the basis for economic relationship is one of trade benefit/necessity rather than subjective friendship), the notion of bridging ties as a unique potential resource conduit between disconnected economic subgroups or communities built upon this premise and was later clarified by Burt's theory on the advantage of structural holes (Burt, 1992).

Burt argues; networks that are sparse and fairly un-clustered allow many opportunities for entrepreneurial brokerage and can thus be thought of as 'entrepreneurial networks'. To obtain these entrepreneurial benefit, there must be an un-exploited potential for knowledge transition to be present within the system, or as Burt puts it: 'the hole itself is an invisible seam of non-redundancy waiting to be discovered by an able entrepreneur (Burt, 1992).

From these opposing theories it can be argued that it is advantageous for individual entrepreneurs to be in one of two positions depending upon network cohesion: Firstly, within problem solving networks, if an actor is centrally placed with strong integration, it helps to increase the resource base of the actor, (in terms of social capital, information flows, technology access, etc.) and, therefore, increase its overall degrees of freedom (Jacobsson and Johnson, 2000). The second advantageous position within networks (especially within emerging industries where there is a high level of structural holes and thus higher potential for network exploitation) is to be a network broker between two non-overlapping different clusters (Burt, 1992, Low and Abrahamson, 1997).

This unifying argument also compliments Low and Abraham's theory of firm maturity. Within early nursing ('problem solving') stages of a high technology sector, initial firms have few strong ties with large 'social capital', ('Movers'). While latter stage companies ('Clones and Bandwagons') who are within maturing sectors (changing to entrepreneurial networks) rely more on ties that cross knowledge gaps and allow for more flexible, adaptable to sectoral disruption and cheaper resources to be pooled from outside their direct periphery (Low and Abrahamson, 1997).

The key points of differentiation therefore between the theories of 'structural hole benefits', as argued by Burt and the theory of 'closed networks' model as argued by Walker *et al*, are; on the onus as to whom the benefits of the network structure are bestowed, (i.e. entrepreneurs or the system as a whole) and the 'functionality' of network (i.e. entrepreneurial or problem solving) (Burt, 1992, Walker *et al.*, 1997). This is shown graphically in Table 1 below.

Network Type:	Network Function	Network Virtues	Spill-over Potential	Entrepreneurial Benefit
Closed/ Dense	Problem Solving	High social capital Lower overall transaction cost More innovative to sector	MAR spillovers from specialisation	Brokerage or Centrality
Open/ Loose	Entrepr-eneurial	More flexible/adaptive to change Higher entrepreneurial opportunity Lower *trade* costs	Jacobian spillovers from diversification	Brokerage

Table 1: Network Comparisons

2.4.4a Metrics for Brokerage: Redundancy and constraint

The two metrics defined by Burt for brokerage within structural holes is redundancy and constraint (Burt, 1992). Redundancy, (as mentioned above) is a measure of how many of ego's alters have relations with each other and therefore how much brokerage power and entrepreneurial opportunity an actor has between them. Constraints however measures the level of susceptibility of demands that ego has from alters within their ego-network through measuring how many structural holes alter has.

The metrics for this analysis are a little complicated (and the notation has been argued by some as ambiguous) a simplified example however of redundancy that works for binary symmetrised networks is provided by Borgatti below the primary equations which helps to illustrate the value of redundancy (Borgatti, 1997).

Redundancy:

The redundancy measure for a node (i) within a network is the summation of the redundancies from each alter node within ego's network. Each alters' (j) redundancy are calculated as shown in Equation 10 below (Burt, 1992):

$$Extent\ of\ j's\ overal\ redundancy\ to\ i's\ network = \sum_q p_{iq} m_{jq}$$

Equation 10: Node's Structural Hole Network Redundancy Measure (Burt, 1992)

Where:

$$p_{iq} = The\ proportion\ of\ i's\ relationship\ with\ q\ (w.r.t.j) = \frac{(z_{iq} + z_{qi})}{[\sum_j (z_{ij} + z_{ji})]}$$
$$= \frac{sum\ of\ iq's\ bi - directional\ relationship}{the\ sum\ of\ all\ i's\ bi - directional\ relationahips}$$

And

$$m_{jq} = \ Marginal\ strength\ of\ j's\ relationship\ with\ q = \frac{(z_{jq} + z_{qj})}{max(z_{jk} + z_{kj})}$$
$$= \frac{sum\ of\ jq's\ bi - directional\ relationship}{the\ maximum\ relation\ in\ j's\ bi - directional\ network}$$

i = ego
j=evaluated node
k=larget relationship node for j
q=target node

Once the redundancy of the network has been calculated, the *effective size* measure of the network can also be calculated which is a summated measure of the *non-redundant* value for ego's network. This is given as:

$$Effective\ size\ of\ i's\ network = \sum_{j}\left[1 - \sum_{q} p_{iq} m_{jq}\right]$$

Equation 11: Node's Structural Hole Effective Size Measure (Burt, 1992)

This measure varies from 1, meaning that all contacts are connected (i.e. you are dealing with one structural group) and that there is no structural opportunity for ego, up to the value of the size of the network, meaning that every alter is disconnected from every other and thus you have strong brokerage opportunities between them.

If the effective size of the network is then divided by the size of ego's network, (i.e. the sum of every node except ego), then an *efficiency* term is produced as defined below:

$$Efficiency\ of\ i's\ network = \frac{\sum_j \left[1 - \sum_q p_{iq} m_{jq}\right]}{N}$$

Equation 12: Node's Structural Hole Efficiency (Burt, 1992)

Where N is the ego-net size.

To help understand redundancy better, Borgatti states that for a binary symmetrised network:

$$redundany = \frac{2 \times number\ of\ ties\ in\ the\ ego\ network\ (excluding\ those\ to\ ego)}{number\ of\ nodes\ in\ ego\ network\ (excluding\ ego)}$$

Equation 13: Simplified Redundancy Measure for Binary Symmetrised Ties

This massive simplification helps to show that the redundancy of a node is proportional to the number of connections ego's alters have, and inversely proportional to the number of alters within ego's network. The equations above (Equation 10 through Equation 12) however work for asymmetric valued ties.

2.5 Conclusive Remarks

This chapter has look thematically and in some depth at the many theories of both economic innovation and social network analysis that shall be applied within the following chapters of this thesis. Some of these are not specifically drawn upon for analysis however having a conceptual understanding of both their existence and contribution to theory will assist in understanding the rationale for some of the research decisions taken when not specifically highlighted within the text. The following chapter, (Background Review of the Sector) provides a system specific assessment of the history of the UK wave energy sector's emergence. It likewise, may not be referenced to specifically within the primary research however also provides contextual understanding but rather of the system itself than the methodologies employed to examine it.

3. Background Review of the UK Wave Energy Sector

Table of Figures:

Table of Tables:

3.1 Chapter Introduction

This chapter provides an introduction and oversight into both the historic development of the UK wave energy sector and also the wider landscape of climate, energy and innovation policy from which the sector has emerged. The historic decisions, policies and events that have formed the evolution of the sector have greatly affected the legacy of wave energy within the UK both in terms of the legitimacy and search heuristics but also with respect to the current backdrop of regulations, planning and other incumbent institutions that stakeholders operate within in order for sectoral commercialisation to occur.

Some aspects of this chapter provide insight that is itself drawn upon within the later, discussion and conclusion chapters however this insight is 'incidental' in that it comes from extensive desktop review of the sector rather than the primary data gathering and methodological assessment outlined within the methodology. Other details, (such as for example amount of public funding spent) have both a historical significance and are assessed further within the 'Established Findings' chapter however, where these overlaps occur, the onus has been to place findings within the methodological framing and referencing has been provided.

3.2 History of the Wave Energy Sector

3.2.1 Early History of the UK Wave Energy Sector

The UK government has been investigating the commercial exploitation of wave energy since the 1970s. Onwards from 1974, the then UK Department of Energy (DEn) committed over £17M to funding its Wave Energy Programme. The funding goal was to establish the feasibility of energy extraction from the ocean, to allow cost estimation at commercial larger scale and ultimately, establish the feasibility of designing a 2GW rated WEC station (using multiple devices). Although 8 devices were taken to the design stage, none of these met the excessively ambitious criteria of the challenge (Thorpe, 1999).

It was during this time that Stephen Salter, an engineer and physicist at the University of Edinburgh started to work on designs for wave energy extraction finally settling upon the Edinburgh Duck (later known as Salter's Duck). Salter's Duck was a cylindrically shaped designed wave 'terminator' that was tapered along one side to form a soft point (see later in this chapter for a more thorough description). Its efficiency of wave energy absorption was around 96% and was seen as the leading design in wave energy converter at the time (Salter, 2008). Salter worked not only on pioneering of device designs but as a result of his work, helped modernise wave test tanks as well as the fundamental understanding of the ways in which energy (both mechanically and electrically) can be extracted and converted from waves. He is now generally regarded as the 'grandfather' of modern wave energy research.

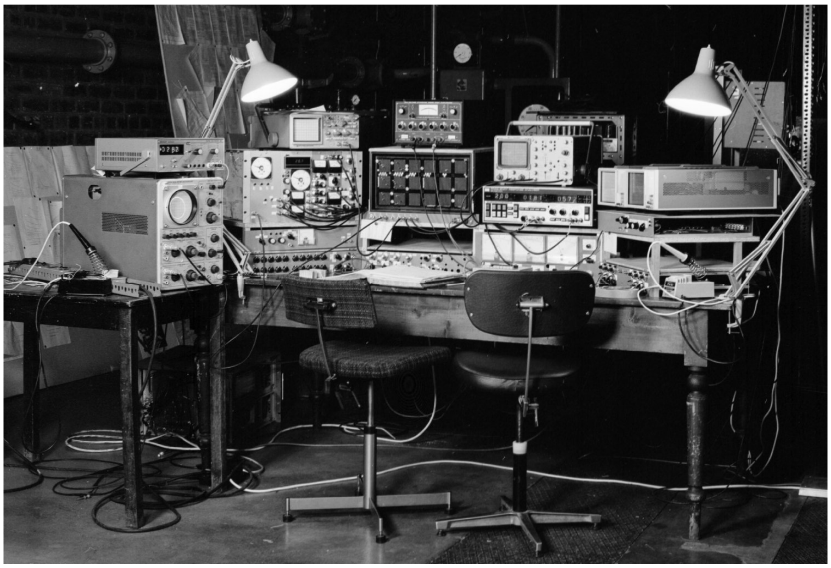


Figure 15: 1975 Stephen Salter's Wave Tank Controls at the University of Edinburgh the Birth of the UK Wave Energy Sector

DEn's advisory committee for energy R&D at the time, the Advisory Council on Research and Development (ACORN) had a specific committee, the Wave Energy Steering Committee (WESC), who advised ACORN, (and in turn DEn) on costs, technical feasibility and other such matters related to the wave energy programme. WESC itself however was made up of member who held other full time roles and relied on six separate consulting groups themselves for information, who specialised in separate fields within the wave energy sector (Salter, 2008). The Government's head of the wave energy programme during this time was Clive Grove-Palmer, a scientist within the UK Atomic Energy Agency (UKAEA) (since the renewable energy programme was itself a sub component of the UKAEA). Grove-Palmer became a strong advocate of wave energy technology after working with Stephen Salter at Edinburgh University on the Edinburgh Duck design (Jeffery, 1990, Ross, 2002).

In 1982, ACORN held a 'closed door meeting' (without Grove-Palmer) in which it was decided to drastically scale down support for the technology following an unpublished government report which predicted that wave energy technology would never feasibly produce energy at a competitive price (Jeffery, 1990, Salter, 2008). There was a great deal of controversy over this decision which advocates of wave energy power have suggested had been motivated by a wider ambition of the Thatcher administration (and UKAEA) to move towards the next generation of nuclear power stations (Salter, 2008, Jeffery, 1990, The Science and Technology Committee, 2001).

After this meeting marine energy research and the technology was downgraded onto a 'technology watch' status by the government and although many smaller devices continued to be funded, financial support declined and the programme was finally abandoned in 1994 in a decision that was later recognised by the Department of Trade and Industry (DTI, now BIS) to have been a mistake (The Science and Technology Committee, 2001, Thorpe, 1999). Over the next few years central government funding for wave energy research was virtually non-existent, decreasing from £100,000 per annum to just £50,000 by 1997. (SPRU, 1999)

The below Figure 16 shows total UK R&D spend on ocean energy (inclusive of wave, tidal and thermal gradient) over this time.

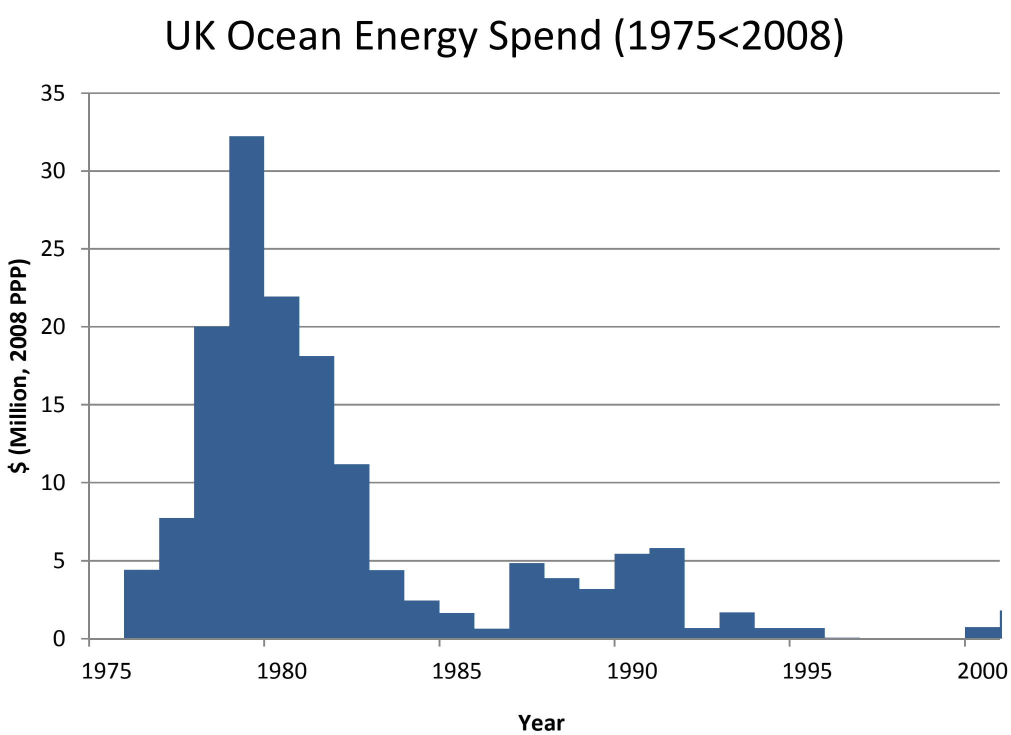


Figure 16: UK Ocean Energy Technology Spend (IEA, 2010)

Despite this strangulation of funding however, throughout the 80s and into the 90s, a wide range of device developer companies emerged, many from the academic research funding that had preceded this financial desert. These designs included the Bristol Cylinder, SEA Clam, PS Frog, McCabe Wave Pump and the Sloped IPS Buoy (Thorpe, 1999). Due to the lack of finance within the sector however, very few of these devices ever got to sea trial with the exception of Applied Research and Technology's (ART) 2MW Ocean Swell Powered Renewable Energy device (OSPREY). This was a near-shore oscillating water column device (see later in this chapter for more information on device types) that was built to full scale in 1995. Unfortunately, due to a structural failure during installation, the device sank before it could be securely moored in a freak storm. This well publicised failure greatly affected the (already beleaguered) credibility of this emerging sector.

In 1997 the fortunes of wave energy began to turn as the Labour party came into power for the first time since the 70s and questions of wave energy viability were bought back into the political domain for the first time in over 15 years.

The end of the century ushered in a new era of interest in wave energy technology. Through the New and Renewable Energy Programme, the DTI began funding wave research again albeit far more modestly than that of the late 70s and early 80s. At the same time, the final of the Scottish Renewables Orders committed to three wave and tidal energy contracts to be delivered at £60-£70/MWh (Renewables Advisory Board, 2008). Only one wave energy device however, Wavegen's (formerly ART) 500kW Limpet device, successfully made it through to operation. This was the first commercial wave energy generator within the UK and is still in operation today.

3.2.2 Recent History of the UK Wave Energy Sector

3.2.2a Financial Support

Since the introduction of the Scottish Renewables Obligation in 1999 and the new focus of interest from the UK government began, there has been several high level funding initiatives geared towards UK wave energy device development. The most notable at the start of the decade was the UK Government's New and Renewable Technology R&D Programme which was established to evaluate the validity of 27 different marine energy devices, (10 of which were wave energy converters) with a budget of £26M (Renewables Advisory Board, 2008).

Alongside these main sources of funding have come a plethora of other funding support programmes from devolved administrations, QUANGOs, differing regional, national and international public sector bodies as well as industry itself. Investigation of these funding streams, their conditionality and application is detailed and discussed further within this thesis as part of the primary research and discussion stages within Chapter 6, Section 6.2.1. however in addition to technology push (grant support) funding the main market pull support system (revenue support), the Renewables Obligation came into place which is discussed later in this chapter.

Alongside these financial instruments over the last decade there have been several other enabling developments for the UK Wave energy sector discussed below.

3.2.2b Test Centres

Possibly the most notable of the non-fiscal industry supporting measures has been the development of three distinct test/demonstrations centres for marine energy devices: The first centre was developed in Orkney, North Scotland and is the European Marine Energy Centre (EMEC). Established in October 2003, EMEC's core remit is to provide a grid connected testing location for full scale marine energy devices (both wave and tidal). Since this time, EMEC has contributed significantly to developing standards for marine technology testing, device consultancy support and specific project R&D (European Marine Energy Centre, 2009a). EMEC was set up initially as a limited company and had received around £14.5M of public support. In 2009, it was awarded a further £8M to assist in expanding sea test facilities (European Marine Energy Centre, 2009a, DECC, 2009).

At the same time EMEC was commissioned, the second test centre to focus on marine renewable energy within the UK, the New and Renewable Energy Centre (NaREC) in Blyth finished construction. NaREC operates as a test facility for a wide range of renewable energy technologies including; wind, tidal, photovoltaic and other low carbon innovation research such as decentralised grid design and planning (New and Renewable Energy Centre, 2011). Within the marine energy sector, NaREC conducts large scaled device testing and development through the use of a large outdoor dry dock facility that they own. They also provide technical consultancy, resource assessment, feasibility studies, due diligence reports, project management, market research and funding co-ordination for device developers, utility and project management companies as well as the UK government. NaREC has to date received around £10M of public funding for marine renewables and the government has recently proposed a further £10M towards marine renewables to build facilities for onshore design and component testing (Renewables Advisory Board, 2008, DECC, 2009).

The final test centre within the UK is based off Hayle in Cornwall and is the newest site of the three, commissioned in late 2010 it is now (June 2012) awaiting its first customer. Wave Hub is a pre-commercial demonstration site designed to allow device developers (potentially in partnership with project development companies or utility companies), to deploy a small array of devices over a long period, (1yr+) to assess overall power generation characteristics, reliability, serviceability and general array feasibility. The advantages of the Wave Hub site is that it lowers risk and cost to developers by providing a ready-to-use site in which the cabling has been installed, environmental baseline monitoring and equipment is already deployed and most licensing and consent issues have been overcome. Technically, the Wave Hub site consists of an $8km^2$ site situated 14km out to sea with a large (12 tonne) subsea connector allowing for up to 5MW of capacity to be installed into each of fourth berths (allowing 20MW overall site capacity). This power is then bought back to the shoreline where it is rectified and transformed before being fed into the national grid.

Figure 17: The 12 Tonne Wave Hub 'Socket' being loaded for deployment in 2010

To date, Wave hub has cost around £42M, making it the most expensive of the UK's test centres, however its role is a 'post-EMEC' demonstration site capable of higher capacity levels of installation. Funding has come from the European Regional Development Fund Convergence Programme (£20M), the South West Regional Development Agency (SWRDA) (£12.5M) and the UK Government (£9.5M) (Clark, 2010).

3.2.2c Current Deployment and Planning Expectations

The UK has a range of commercial non-test sites at various stages in the planning process. Perhaps one of the most advanced one of these (besides the Limpet site which is effectively now running as a grid connected test centre for turbine designs) is the Siadar Bay Wave Energy Project (SWEP) in Scotland. This 250m long wave energy converter involves 40 oscillating water column devices built within a breakwater and a total rated capacity of 4MW. The project was given planning consent in January 2009. NPower Renewables is currently in talks with suppliers over equipment options and see this project as their flagship wave energy development (Scottish Government, 2009a, RWE NPower Renewables, 2007).

The largest leased deployment site currently underway is the Pentland Firth Development (see Figure 18 below). This site, effectively seen as the 'Round One' of wave and tidal energy, is currently the largest scale deployment project planned in the world. Proposed, tendered and managed by the Crown Estates, the Pentland Firth Development consists of a collection of 10 different deployment locations, (five wave energy and five tidal) amounting to a potential of 1.2GW of installable capacity, (600MW Wave and 600MW Tidal) (Crown Estate, 2010a).

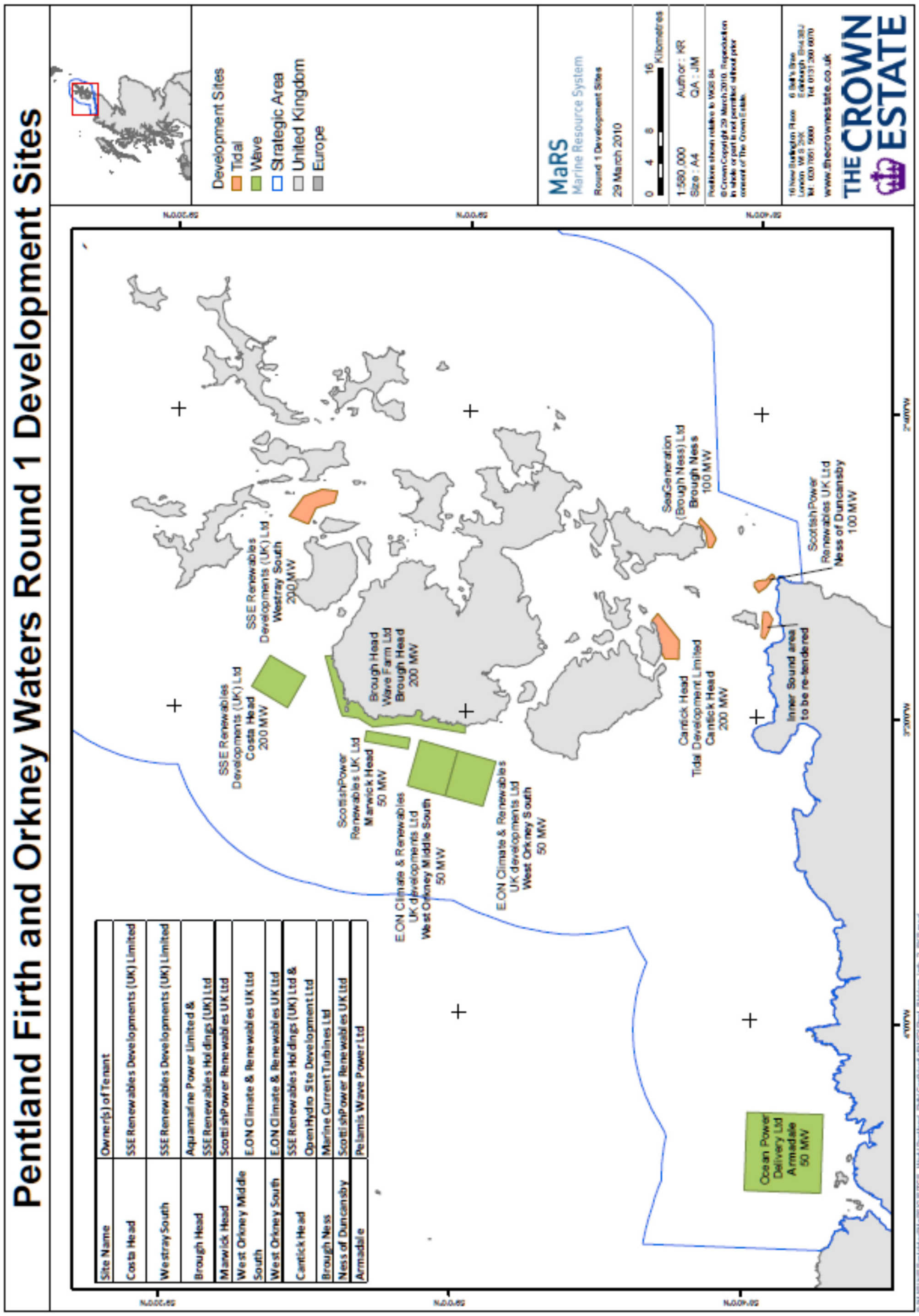


Figure 18: Pentland Firth Development Sites (Crown Estate, 2010)

Leasing for this site was announced in 2010 following an extensive tendering process and the wave energy sites were allocated as show in Figure 18 and Table 2 as follows:

Site Name Owner(s) of Tenant	Owner(s) of Tenant	Leasing Capacity
Costa Head	SSE Renewables Developments (UK) Limited	200MW
Brough Head	Aquamarine Power Limited & SSE Renewables Holdings (UK) Ltd	200MW
Marwick Head	Scottish Power Renewables UK Ltd	50MW
West Orkney Middle South	E.ON Climate & Renewables UK Ltd	100MW
Armadale	Pelamis Wave Power Ltd	50MW

Table 2: Pentland Firth Development Sites (The Crown Estate, 2010a)

Although not a requirement, the majority of wave energy sites were initially tendered for by utility companies in partnership with device developers with the belief that this would allow tenders to provide a stronger financial and technical assurance of deployment (since the resources of most utility companies dwarf that of the average device developer).

The Pentland Firth development has placed Scotland centre-stage on the marine energy development map, and the combined deployment challenges have bought about a large level of interest from regional universities, consultant/engineering companies and politicians seeking to assist and associate themselves with this landmark project.

In addition to the Pentland Firth developments, The Crown Estates have also opened up the Scottish waters that it manages to other marine development projects, these it refers to as Saltire Prize Projects due to the fact that those developing projects would most likely be doing so for the purpose of winning the Saltire Prize, (see the Resource Mobilisation section (6.2) of chapter 6, (Established Findings) for more information. As of June 2011, the only wave energy development to be proposed under this scheme is the Shetland Project, a 10-20MW development off the coast of the Shetlands connected to mainland Scotland via a high voltage, direct current line, (HVDC). This project is being developed by the project development company Aegir Wave Power, a collaborative affiliation between Pelamis Wave Power Ltd and the large Swedish State utility company, Vattenfall. The aim of this project is to deploy 14 Pelamis machines off the south west of Shetland by 2014 with a future upgrading to 26 devices if the first stage is successful.

3.2.2d Overview of Marine Technology

Although this thesis has purposely avoided focusing on the many technical aspects of wave energy, a brief description of how wave energy works, what device classifications and types exist and how they operate is provided as a reference. Having a basic understanding of the technology is extremely advantageous when assessing the sector from a systemic perspective as the pros & cons, innovative appropriability (as Dosi refers to it (Dosi *et al.*, 2006a)) and heterogeneity of the technology type have clearly had a substantial influence upon the formation of both the deployment and planning regime for wave technologies and also the structure of the market itself.

3.2.2e Classification of Wave Energy Devices

There are a multitude of methods and ways to describe wave energy systems and a vast array of wave energy devices currently being researched. This can cause confusion when trying to assess not only the merits and demerits of various sub-categories of wave energy device, but also when trying to get a clearer understanding as to where the sector is moving and what the most successful technology groups are. Commonly, the definition may be made according to the most desirable information being sought. So for example; an environmental consultant may describe a device by its location and mooring type, (e.g. near-shore seabed fixed device) whereas a technology analyst would be likely to use a more formalised (although not necessarily more descriptive) classification systems such as the patent classification or by its power take-off mechanism. Various methods for categorising devices that are regularly used are listed below, however no particular method is fully descriptive and in most cases, to get a good understanding of a device, several descriptive classifications must be used in conjunction:

Classification by Patent Type:

There are three patent classification systems, the International Patent Classification (IPC), the United States Patent Classification (USPC) and the European Classification (ECLA) system. Although each of these patent classification systems are slightly different, (the ECLA for example is more descriptive and holds twice as many categories as the IPC for instance)

Wave energy is covered by taxonomies in the following classification systems:

International Patent Classification:

Adaptations of machines or engines for special use; Combinations of machines or engines with driving or driven apparatus; Power stations or aggregates

F03B 13/14 - using wave energy

F03B 13/16 - using the relative movement between a wave-operated member and another member

F03B 13/18 - wherein the other member is fixed, at least at one point, with respect to the sea bed or shore

F03B 13/20 - wherein both members are movable relative to the sea bed or shore

European Classification:

Adaptations of machines or engines for special use; Combinations of machines or engines with driving or driven apparatus; Power stations or aggregates

- F03B13/14 - using wave energy
    - F03B13/14B - with a static energy collector
        - F03B13/14B2 - which creates an oscillating water column
        - F03B13/14B4 - which lifts water above sea level
            - F03B13/14B4B - for immediate use in an energy converter
            - F03B13/14B4D - for later use
    - F03B13/14C - using the static pressure increase due to the wave
- F03B13/16 - using the relative movement between a wave-operated member, [N: i.e. a "wom"] and another member, i.e. a reaction member or "rem"
- F03B13/18 - where the other member, (i.e. rem) is fixed, at least at one point, with respect to the sea bed or shore
    - F03B13/18B - and the wom is hinged to the rem
        - F03B13/18B2 - for limited rotation
            - F03B13/18B2B - with an up-and-down movement
            - F03B13/18B2D - with a to-and-fro movement
        - F03B13/18B2 – for 360 degree rotation
            - F03B13/18B4B - of a turbine-like wom
            - F03B13/18B4D - of an endless-belt type wom
            - F03B13/18B4F - of a water-wheel type wom
    - F03B13/18D - and the wom slides relative to the rem
        - F03B13/18D4 - not vertically
        - F03B13/18D6 - where the connection between wom and conversion system takes tension and compression
            - F03B13/18D6B - the connection being of the rack-and-pinion type
        - F03B13/18D8 - where the connection between wom and conversion system takes tension only
        - F03B13/18D10 - and the wom directly actuates the piston of a pump
        - F03B13/18D12 - and the wom is the piston or the cylinder in a pump
    - F03B13/18F - and the wom is flexible or deformable
    - F03B13/18H - and the wom is tied to the rem
        - F03B13/18H4 - where the tie is a tension/compression member
- F03B13/20 - wherein both members (i.e. wom and rem) are movable relative to the sea bed or shore
- F03B13/22 - using the flow of water resulting from wave movements to drive a motor or turbine

- F03B13/24 - to produce a flow of air, e.g. to drive an air turbine

United States Patent Classification:

325 Pressure Fluid Source and Motor:

Apparatus having a means or source capable of flowing or pressurizing a liquid or gaseous motive fluid, and motor means responsive to the pressure of the flow or of the fluid to convert such pressure or flow to useful mechanical work, said motive fluid being capable of transmitting energy from said source to said motor

327 Methods of operation:

398 Utilizing natural energy or having a geographic feature:

Apparatus physically related to some feature of the earth or in which pressure or kinetic energy of nature energizes motive fluid.

Note. This subclass includes devices providing a head of liquid that furnishes pressurized motive fluid to a motor

495 Motor Having a Buoyant Working Member:

Apparatus having a working member which may be made buoyant or which is buoyant in a fluid and which may be caused to be moved by the fluid, because of the difference in specific gravity between the member and the fluid, to have a vertical component of motion and thereby adapted to do work, through a mechanical output means, either (1) because of a means which may make said buoyant member more or less buoyant so that it may be moved either against or by the pull of gravity in said fluid, or (2) though its specific gravity remains constant, the buoyant member may be given a vertical component of motion as a result of the rise and fall of the surface of said fluid.

496 - With means to vary buoyancy of working member:

497 - Working member actuated by the rise and fall of a surface of a body of fluid:

498 - Having tide responsive working member positioning means:

499 - Having means responsive to lateral impulse of fluid:

500 - Having articulated buoyant members:

501 - Motor is free floating unit:

502 - Motor is free floating unit:

503 - Motor is free floating unit:

504 - Having flexible strand working member motion transmitting means:

505 - Having relatively movable working members:

506 - Working member pivotally supported:

507 - Having one-way clutch power transmission means, e.g., ratchet, etc.:

As can be seen from the various patent classification types, the level of detail and descriptive value of the classifications vary depending upon the location of the patent classification. Additionally, certain patent classifications will naturally overlap (such as for example when a device is an oscillating water column that is floating above the sea bed) and can therefore lead to duplicate classification.

(World International Patent Office, 2010, European Patent Office, 2010, United States Patent and Trademarking Office, 2010)

Classification by Primary Means of Power Conversion:

One of the most common forms of categorisation used for wave energy devices is based upon their power conversion system. The main forms of energy conversion currently being researched are:

Hydraulic Power Take-Off:

Hydraulic power take-off mechanisms operate on the principle of a fluid such as sea-water or oil being pumped around a system, (closed or opened) as the result of a resistive movement caused by the wave interaction with the device. Typically this could mean a part of the device is fixed to the sea-bed, (as with Aquamarine's Oyster system) or that two separate moving parts interact in opposing fashion, (as with Pelamis Wave Power's Pelamis system). Hydraulic power take off mechanisms may use an intermediary such as a pneumatic system (as with Sea Energy Associate's SEA Clam design).

Magnetic Power Take Off:

The primary design for a magnetic power take off is some form of linear point absorbing device that has a stator and translator that move in opposition to each other such that a current is induced within the stator. Two of the primary advantages of this form of energy conversion are that it can be omnidirectional and that it minimises the amount of moving components within the system. Examples of the magnetic power take off systems include Trident Energy's linear generator and Seabased's sub-sea wave energy converter.

Oscillating Water Column (OWC):

Currently one of the most technologically mature technology categories, oscillating water column devices work on the principle of energy extraction through a wells turbine due to a build-up of air pressure created through the wave movement. This therefore needs an air chamber in contact with the water through which the wave can pass. As it does so, the volume of air in the chamber is pressurized through the turbine. The main advantages of an OWC design is that the movable element of the device, (the turbine etc) can be kept out of the water and that the structure itself can be designed into a breakwater or shoreline location reducing the capital cost of these projects. Examples of OWC systems include Voith Hydro Wavegen's Limpet and the Japanese Agency for Marine-Earth Science and Technology's (JAMSTEC) Mighty Whale.

Overtopping Device:

This final type of power extraction works on the principles of creating a physical ramp (usually with a channelling component along the sides) up which the wave crest travels into a storage reservoir. This is then driven through a low-head turbine back to sea level. The main advantages of this design type is that, like the OWC design, it can be shoreline based and thus beneficial from a cost bases and, since the reservoir can retain a certain amount of water, can have a more stable power output. Examples of an overtopping device design include Wave Dragon's eponymous device.

Classification by Orientation:

Classification by orientation is useful when considering special, marine environmental and navigational properties of a device.

Attenuator:

These are devices that lie in-line with the incident wave direction of travel, typically trying to maximise the power extraction from a narrow width of wave energy incident upon the 'front' of the device. Examples of this type of device include Checkmate Energy's Anaconda and Vigor Wave Energy's (also eponymous) device.

Point Absorber:

Often (but not always) used with a linear generator design. A point absorber is an omnidirectional device which removes energy from the heave motion of the waves. A point absorber can be positioned above, at or below the sea surface, pushing a buoyant membrane in a vertical motion. Examples include Ocean Power Technology's PowerBuoy or Wave Star's Wave Star machine.

Terminator:

Terminators aim to absorb a wider band of the wave energy along the beam of the device; this is usually done through an overtopping system or a flap however can be based on some internal bearing based movement as with the Salter's duck. Examples of terminators include the Langlee Wave Power's Langlee power convertor or Aquamarine Power's Oyster.

Classification by Depth of Water:

When thinking about both marine spatial planning as well as larger projections of practically available wave energy resource, an understanding of the water depths under which the devices are designed to be deployed is clearly essential. There are only three categories for this:

Onshore:

This is devices that are on the shoreline and use the wave energy break to create energy, such as Voith Hydro Wavegen's Limpet.

Nearshore:

Nearshore devices fall within the range of around 10m depth and tend to be fixed to the seabed in at least one point. These devices include Green Cat Renewable's Green Cat Turbine and Neptune Renewable Energy's Neptune Triton.

Offshore:

Offshore devices refer to those that use deep water location usually with a flexible mooring system to keep them in situ. The advantage of offshore devices is that there is a much higher resource offshore in both terms of physically suitable locations and also based on average kW/m wave height. Examples of Offshore devices include Offshore Wave Energy's, OWEL Grampus.

(Brooke, 2003, Thomas, 2008)

3.2.2f Devices Developers

Throughout the 80s and 90s, when UK marine renewable research was receiving little government support, (see earlier in this chapter) other countries forged ahead with research spending large sums on applied research. Wave energy devices are therefore being investigated globally.

Although the UK has a relatively high number of device developers, other nations with a considerable amount of research activity include; the United States, Canada, Australia, Denmark and many other European countries. Further exploration of current device developer numbers/statistics is explored within the Entrepreneurial Experimentation section of the Established Findings Chapter.

3.3 Policy and Regulation

3.3.1 Introduction

Institutional (in terms of legal frameworks and support) policies relevant to the emergence of the UK wave energy sector are both plentiful and heterogeneous as both the policy and regulation cover not only electrical generation and planning but also renewable energy and innovation technology support policies, and property ownership as well as health and safety, environmental, and electrical regulations. Add to this the implicit complexity of applying this multitude of dimensions both from varying institutional scales (i.e. international, national and regional policies/regulations) as well as onto varying legal geographic boundaries (i.e. onshore, territorial waters, exclusive economic zones and beyond) and an extremely complex legal and support policy landscape is formed. Since the primary focus of work within this thesis looks at actor specific innovation support and behaviour, this section is intended to provide an overview of the institutional conditionality in which the marine energy sector is located and is broken into three logical thematic section covering; climate change and renewable energy, technology innovation and economic growth, maritime regulations and ownership. Many of the finer details (e.g. levels of support funding, RE deployment etc.) are covered at a deeper level in more relevant chapters and sections of the thesis however it is hoped that this area shall provide a current (as of March 2011) overview.

3.3.2 Key UK Renewable Energy Support Mechanisms

The current mechanism used for promoting renewable energy within the UK is the Renewables Obligation (RO) scheme (and microgen feed-in tariff). Set up in 2002 as a replacement for the NFFO, the RO places a regulatory obligation upon electricity supply companies to ensure that an annually specified percentage of the electricity they supply was sourced from renewable sources including wind, solar, wave, tidal and combustible renewables including biomass, landfill and sewage gas and co-firing and small hydro (excluding hydro power stations above 20MW or in operation on or before 31 December 1989 ((Ofgem, 2007)). Electricity generators receive renewable obligation certifications (ROC) for each MWh of RE generation that they produce and can then either sell this certificate with their electricity to the supplier, or separately to another supplier or independent ROC trader. Suppliers must accrue and submit enough certificates to the regulator, (OFGEM) for the stated percentage of the obligation target of electricity supply for that year. Should the supplier fail to provide enough ROCs to meet its supply, it must pay a buyout fee for each ROC that it fails to submit. The buyout fee increases with inflation every year and all proceeds to the fund go into a buy out fund which is re-distributed to suppliers in proportion to the ROCs submitted in that year. Each year the target is raised roughly by 1% with the initial targets for the period 2002-2003 starting at 3% as shown in Table 3.

Obligation period	Percentage of total supplies
1st April 2002 to 31st March 2003	3
1st April 2003 to 31st March 2004	4.3
1st April 2004 to 31st March 2005	4.9
1st April 2005 to 31st March 2006	5.5
1st April 2006 to 31st March 2007	6.7
1st April 2007 to 31st March 2008	7.9
1st April 2008 to 31st March 2009	9.1
1st April 2009 to 31st March 2010	9.7
1st April 2010 to 31st March 2011	10.4
1st April 2010 to 31st March 2012	11.4
1st April 2010 to 31st March 2013	12.4
1st April 2010 to 31st March 2014	13.4
1st April 2010 to 31st March 2015	14.4
1st April 2010 to 31st March 2016	15.4

Table 3: UK Renewables Obligation Levels (UK Government, 2002, UK Government, 2009a)

So far the ROC method can only be said to have failed on its delivery targets. Renewables provided just 5.5% of total electricity demand in 2008, a significant increase of 0.6% on the year before; however the targets of 10% by 2010 seem clearly unattainable (DECC, 2010a).

More recently, the UK government has altered the support mechanism somewhat to provide 'banding' to different technologies. Through this banded ROC system, more mature technologies, (such as landfill gas and co-firing) will receive less support, (0.25ROC/MWh & 0.5ROC/MWh respectively), while less developed technologies such as offshore wind, wave, tidal and solar, will receive higher levels of support (1.5 ROC/MWh for offshore wind and 2 ROC/MW for the remaining). It is hoped by the government that this banding will promote a more diverse renewable energy portfolio while preventing over subsidisation to mature and existing technologies. (DECC, 2008). See Table 4.

<table>
<tr><th>Generation type</th><th>Amount of electricity to be stated in a renewables obligation certificate</th></tr>
<tr><td>Electricity generated from landfill gas</td><td>4 megawatt hours</td></tr>
<tr><td>Electricity generated from sewage gas</td><td rowspan="2">2 megawatt hours</td></tr>
<tr><td>Co-firing of biomass</td></tr>
<tr><td>Onshore wind</td><td rowspan="8">1 megawatt hour</td></tr>
<tr><td>Hydro-electric</td></tr>
<tr><td>Co-firing of energy crops</td></tr>
<tr><td>Energy from waste with CHP</td></tr>
<tr><td>Geopressure</td></tr>
<tr><td>Co-firing of biomass with CHP</td></tr>
<tr><td>Standard gasification</td></tr>
<tr><td>Standard pyrolysis</td></tr>
<tr><td>Offshore wind</td><td rowspan="3">0.66 megawatt hour</td></tr>
<tr><td>Dedicated biomass</td></tr>
<tr><td>Co-firing of energy crops with CHP</td></tr>
<tr><td>Wave</td><td rowspan="13">0.5 megawatt hour</td></tr>
<tr><td>Tidal-stream</td></tr>
<tr><td>Advanced gasification</td></tr>
<tr><td>Advanced pyrolysis</td></tr>
<tr><td>AD</td></tr>
<tr><td>Dedicated energy crops</td></tr>
<tr><td>Dedicated biomass with CHP</td></tr>
<tr><td>Dedicated energy crops with CHP</td></tr>
<tr><td>Solar photovoltaic</td></tr>
<tr><td>Geothermal</td></tr>
<tr><td>Tidal impoundment – tidal barrage</td></tr>
<tr><td>Tidal impoundment – tidal lagoon</td></tr>
</table>

Table 4: Amount of Electricity To Be Stated In ROCs (UK Government, 2009a)

As of June 2011, the RO banding mechanism is currently under review and levels of subsidy are thought likely to change during the publication of the review outcome. Levels of deployment however reached through the main two support mechanisms, (the NFFO and RO) to date are shown in Figure 19 below:

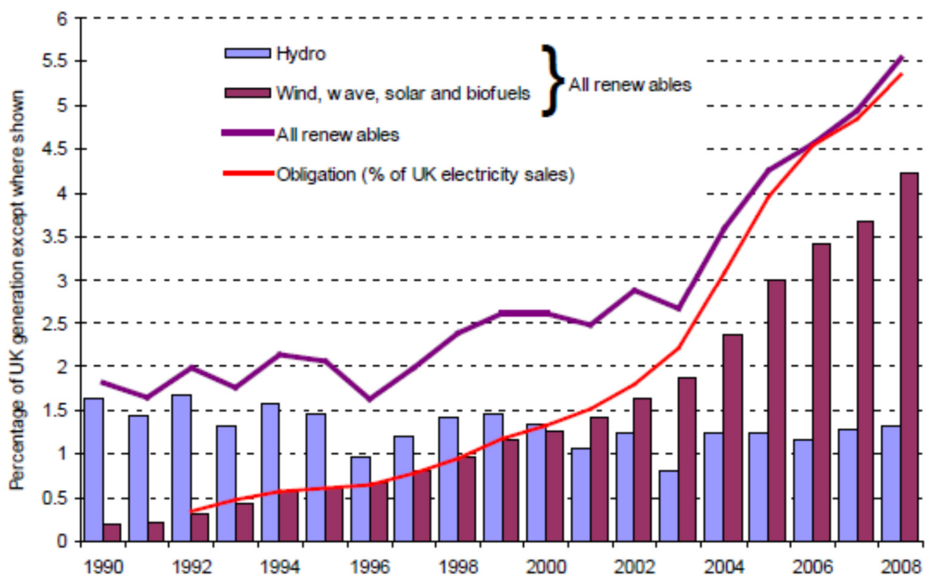


Figure 19 Renewable Electricity Generation 1990-2008, (DECC, 2010a)

Another form of support for renewable energy generation within the UK include Climate Change Levy (CCL), Levy Exemption Certificates (LECs). In 2001, the government decided to introduce a tax levy on all industrial and commercial users of electricity to both promote energy reduction and renewable energy and also fund climate change policies. As of April 2011, this levy is set at £4.85/MWh however ofgem accredited generators of renewable energy can receive electronic exemption certificates (issued by ofgem) that can then be traded and submitted to HM Revenue and Customs for exemption on a per MWh basis of electricity used (Ofgem, 2011).

In addition to the above revenue support mechanisms there are a wide range of grant support (technology push) support mechanisms which are specific for differing technologies. These are explored further within the Established Findings chapter of this thesis.

A timeline summary of the key UK revenue support mechanisms for renewable energy is provided in Table 5 below.

England				Scotland		
Agent	Tradable	Mechanism	Year	Mechanism	Tradable	Agent
NFPA	NFFO Contracts	NFFO 1	1990			
NFPA	NFFO Contracts	NFFO 2	1991			
			1992			
			1993			
NFPA	NFFO Contracts	NFFO 3	1994	SRO contracts	SRO 1	SSE Energy and Scot. Power
			1995			
			1996			
NFPA	NFFO Contracts	NFFO 4	1997	SRO contracts	SRO 2	SSE Energy and Scot. Power
NFPA	NFFO Contracts	NFFO 5	1998			
			1999	SRO contracts	SRO 3	SSE Energy and Scot. Power
			2000			
ofgem	LECs	CCL	2001	CCL	LECs	Ofgem
ofgem	ROCs	ROO	2002	ROO(S)	ROSCs	Ofgem
ofgem	REGOs		2003		REGOs	Ofgem
			2004			
			2005			
			2006			NFPA Scotland (Replaces SSE &SP)
			2007			
ofgem	ROCs	Banded ROO	2008	Banded ROO(S)		Ofgem

Table 5: UK Renewable Energy Revenue Support Timeline

3.3.3 Technology Innovation and Economic Growth

Technology support mechanisms for marine renewable energy, as a core focus of this thesis are discussed in much greater detail within the Resource Mobilisation section of the Established Findings Chapter (section 6.2). A background introduction into the UK government's innovation support structure and main bodies is provided here however for reference. A more detailed theoretical overview of innovation studies is also provided within the Literature Review.

3.3.3a National Innovation Policy

Official methods for Innovation support from government have been present from the very early part of the 20th century through various government support bodies which have at times considered skills, innovation, trade and energy within the remit of their research. For example, during the period from 1992 till 2007, the Department of Trade and Industry held a wide portfolio of responsibilities ranging from innovation, energy, trade and science to business growth, regulatory and consumer laws (The National Archives, 2010). Only a year later however (by 2008), these responsibilities had been split between three separate central government departments. A timeline of the key UK departments relevant to innovation within the energy sector (inclusive of skills and education) is shown in Figure 20 below.

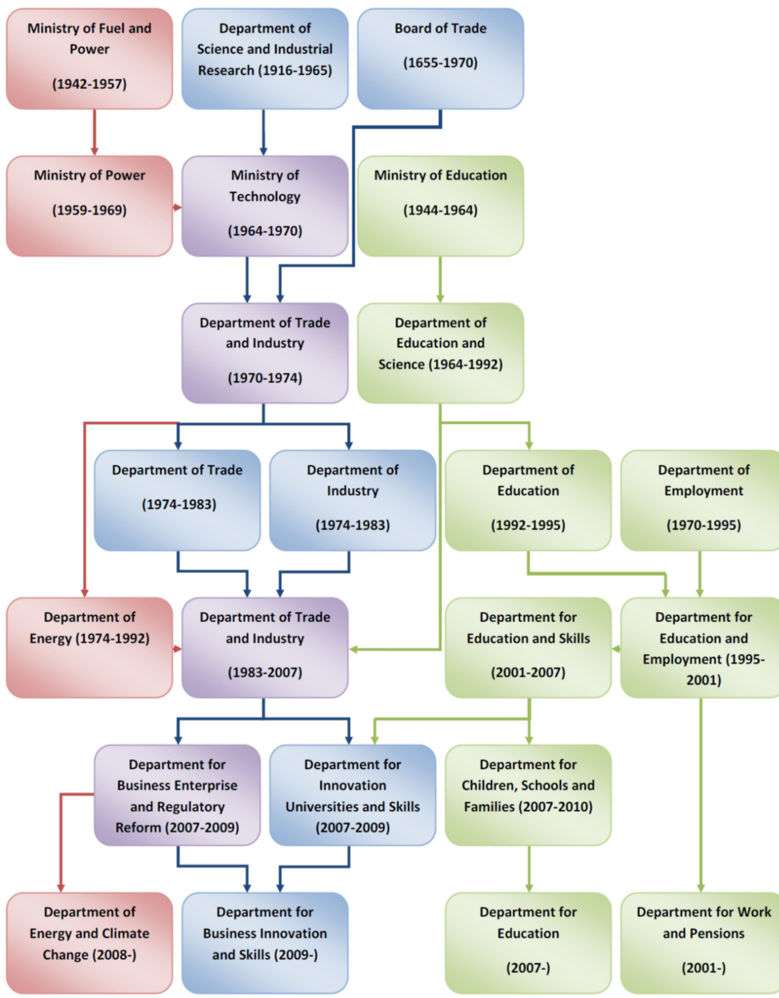


Figure 20: Key UK Departments Responsible for Innovation and Skills within the Energy Sector[1]

The birth of research into wave energy came around in the 1970s when the newly formed Department of Energy began investigating alternative forms of energy generation as a result of

[1] This figure excludes devolved departments within Scotland, Wales and Northern Ireland as well as non-central government departments. Key: Red – Energy, Blue – Innovation/Trade, Green – Employment/Skills, Purple – Energy & Innovation

the 1973 oil crisis (see the beginning of this chapter for more detail). Since then the predominant funding body for energy innovation has followed the responsibility for energy generation to the Department of Trade and Industry, to the department for Business, Enterprise and Regulatory Reform (BERR) and on to the current Department of Energy and Climate Change (DECC), notably separating it from the now department of Business Innovation and Skills (BIS).

Current government funding allocated into the renewable energy comes from a variety of central government and non-departmental public bodies (NDPs) as well as devolved administrations and government established not-for-profit companies.

As of February 2011, there were a total of 11 NDPB, (4 executive and 6 advisory and the public incorporated Nuclear Liabilities Fund) employing over 1500 staff operating under the oversight of DECC who held budget of £3.16bn (DECC, 2011a, Rogers *et al.*, 2011). Of these, the Committee on Climate Change, the Advisory Committee on Carbon Abatement Technologies and the Renewables Advisory Board were involved in increasing understanding and the promotion of low carbon technologies. None however had a direct role in financing low carbon initiatives and since the 2010 election, only the Committee on Climate Change is still active. DECC do currently fund the Carbon Trust, a government established not-for-profit company whose remit is to; "provide specialist support to help business and the public sector cut carbon emissions, save energy and commercialise low carbon technologies" (Carbon Trust, 2011a). This is done through a combined process of direct financing of R&D and specific deployments, setting benchmarking standards for industry, providing supporting advice to both customers and technology developers and assisting industrial growth through the creation of industrial collaborations and other cost reduction methods.

The Department for Business, Innovation and Skills (BIS) by contrast provided over £260m of support to the Technology Strategy Board (TSB) and over £782m to the Engineering and Physical Science Research Council (EPSRC), the primary UK funder for energy technology research between June 2010 and May 2011 (BIS, 2011a). Further detail of research support funding specifically for wave energy is outlined within the Resource Mobilisation section of the Established Findings chapter, (6.2). A breakdown of the central methods for delivery of direct support for renewable energy technologies is shown in Figure 21 below[2]:

---

[2] NB. The government is currently in the process of transitioning responsibilities for all 9 Regional Development Agencies (RDAs) which is plans to abolish in March 2012.

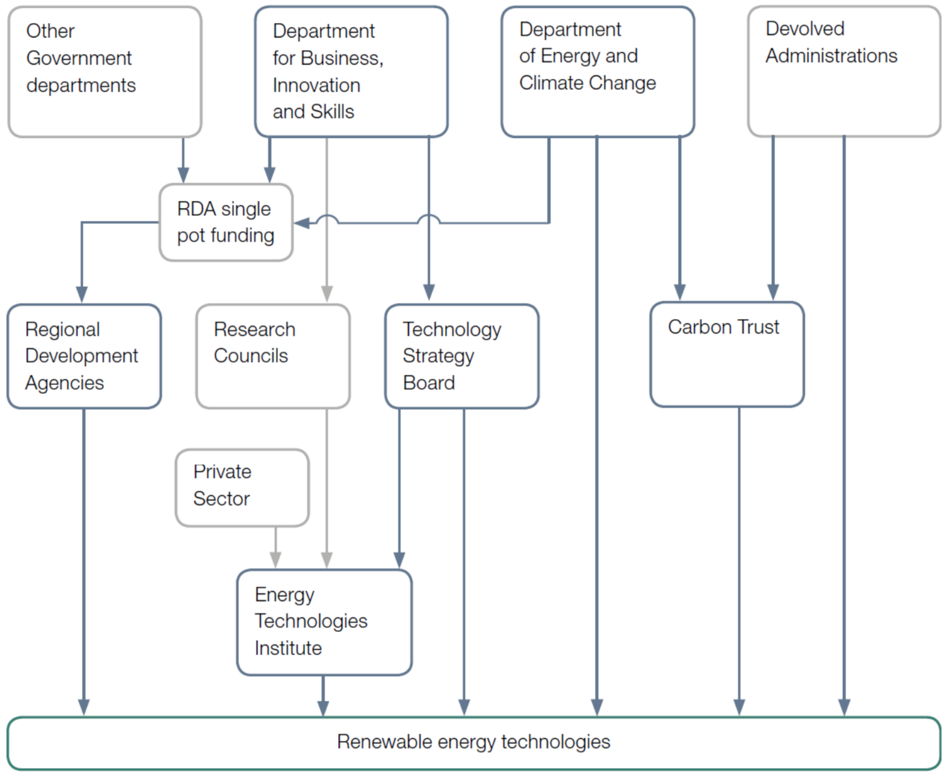


Figure 21: Funding Diagram for Direct Support of Renewable Energy Technologies (National Audit Office, 2010)

3.3.3b Devolution and Regionalised Innovation Policy

There are currently two distinct shifts in focus within UK politics that have had a strong effect on regional RE innovation policy: A shift towards decentralised governments in Scotland and Wales and the abolition of the Regional Development Agencies.

The Scotland Act (1998) established the legislative power of the Scottish Executive (now the Scottish Government). At this time, the Scottish Executive was allowed full de facto legislative control of Scotland except where explicitly reserved (this in practice however was an extensive list of reservations that effectively allow for part-devolution). Within these exceptions are the generation, transmission, distribution and supply of electricity as well as the Electricity Act 1989 (Part II) (See Electrical Connectivity and Operation section below). Explicitly exempt however is the Scottish Government's power to give; *"financial assistance to commercial activities for the purpose of promoting or sustaining economic development or employment"* (UK Government, 1998a) effectively allowing Scotland to have its own technology innovation policy. Wales followed a similar timescale for devolution with the Government of Wales Act 1998 however this established a Welsh Assembly which had far less devolved authority until the Government of Wales Act 2006 instated an executive agency, (now the Welsh Government). Unlike Scotland, even after the 2006 Act, de facto legislative power within

Wales is still held by the UK Government, though broad areas are outlined in which legislative control is devolved including *"economic development"* and *"environment"* (UK Government, 2006) effectively giving similar levels of independence as Scotland in matters of RE economic development.

The second major development is the abolition of the nine Regional Development Agencies established by Labour in 1999 specifically for the purpose of assisting economic development, increasing business competitiveness, skills and employment, and contributing towards a transition towards sustainable development within their region (UK Government, 1998b). Their relative levels of success have been varied, however they have played a key role in some regional renewable energy programmes, for example as with the South West Regional Development Agency instigation (and funding) of the Wave Hub test site (Wave Hub, 2011). These RDA's however will be closed in March 2012 with responsibility for different aspects being passed both locally (to local councils) and nationally for key assets (such as Wave Hub and NAREC which are expected to be managed by BIS initially). This will clearly have an influence upon the development strategies adopted by these research assets (since they may alter from being economically 'stand-alone' initiatives to national assets) as well as the regions themselves (since these regional initiatives for sustainability and innovation will be either abolished or moved to council/national scale focus).

3.3.4 Maritime Environmental Regulations, Planning and Ownership

Marine environmental regulations and planning are one of the key existing regulatory and legal areas that affect the commercialising of the marine renewable energy sector and therefore ensuring that they are aligned to the commercialisation process of the sector, (albeit while fulfilling their primary functionality of marine spatial planning and environmental protection) is essential if the sector is to develop.

The UK marine area covers 867,400km^2, roughly 3.5 times the size of its terrestrial area and was estimated to be worth £46b between 2005-2006 (POST, 2011). As such, the effective management and planning of this resource is considered to be of key strategic importance to the UK. Although technically water within cannot legally be owned (and thus the sea water itself is un-owned), the UK seabed as well as the coastal foreshore is owned or managed primarily by a few key actors.

The foreshore is defined as the area between the mean high water and mean low water of average tides (Ordnance Survey, 2010) and is owned by a multitude of stakeholders but primarily the Crown Estates, (who own 55% of it) as well as the National Trust who own 700 miles of coastline (Hamlyn, 2009).

Historically, under the 1982 United Nations Convention on the Law of the Sea (UNCLOS), territorial seas around the UK coast, (measured from the low water line) extends up to 12 nautical miles (nm). Within this jurisdiction, UK domestic law applies just as it does on land. Although this seabed is national property, its management and full 'landowner' rights are bestowed to the Crown Estates (Under the Crown Estates Act 1961). This means that in practical terms, all leasing for any use (except for hydrocarbons; oil, gas and coal) of the seabed within this region is given through the Crown Estates.

Between this 12nm territorial water line and 200nm, the UK has a designated exclusive economic zone (EEZ) which was established in 2009 through the passing of the Marine and Coastal Access Act 2009 (MCAA). Before this time the UK had an internationally unique, designated Renewable Energy Zone (REZ) which was put in place as a result of the Energy Act 2004 allowing for the provision of offshore wind developments that took place on its Continental Shelf (the definition of 'Continental Shelf' within international maritime law is up to 200nm from a country's coastline out to sea *regardless* of the oceanic morphology (United Nations, 1982a)). Although this region is not subject to UK laws in the same way that territorial waters are, EEZ designation allows for the commercial exploitation of UK waters including "the production of energy from the water, currents and winds" up until the 200nm limit (United Nations, 1982b). Provision however must given for the 'rights of innocent passage' which may be regulated (such as through managed shipping lanes) but not extinguished. The EEZ is also currently managed by the Crown Estates who issue licensing (rather than leases) within this area.

Past the EEZ, beyond 200nm are the high seas which are considered open to all states and free for the purpose of navigation, construction of installations and fishing among other things however. As both international laws apply within this region and the practicality of deploying marine renewables are economically prohibitive, there is currently no major interests in RE deployment within this region.

3.3.4a Marine Planning Policy

Historically, planning consents for marine energy developments within the UK has been lengthy, high in uncertainty and cost with the UK's Wave Hub site taking over 2 years, 25 studies and over £1m of research before consenting was permitted (Lavender, 2010, POST, 2009). This does not include any actual deployment at the site.

The newly created Marine Management Organisation (MMO) is responsible for the application process with regards to a marine licence for all marine renewable energy projects (except within Scottish territorial or Scottish EEZ waters) between 1MW and 100MW (Above 100MW deployments are managed by the Infrastructural Planning Commission). This licence applies to deployment with UK territorial and EEZ waters and is required alongside Crown Estates leasing rights and onshore planning permission (governed under the Town and Country Planning Act 1990) for cables etc. bought to shore.

The Marine Licence encompasses some previously fragmented legislation that was brought under the licences remit and the MMO in an attempt to streamline and clarify the planning process to developers. These previous licences included the following:

- Food and Environmental Protection Act Licence (1985) (FEPA 85): A FEPA licence is required for depositing cables or structures either on the sea bed or within the water column.
- Coastal Protection Act (Section 34 1949) (CPA 49): The CPA governs the safety of navigation and environmental issues.
- Council Directive 94/43/EC (Habitats Directive): The Habitats directive covers the conservation of natural habitats, marine flora and fauna.

Additionally, the Electricity Act (Section 36, 1989) (EA 89) governs the licensing of all energy generation within the sea between 1MW and 100MW and is described in further detail in the Electrical Grids and Regimes section below. Although it is thought that this will become part of the remit of the MMO in future, it is currently managed by DECC. Other licences and consents may be required depending upon the scope, scale and location of the deployment such as European Protected Species (EPS) Licensing should it be deemed necessary during the consultation process.

Responsibilities within Scottish, Welsh and Northern Irish water have been devolved and are managed by Marine Scotland, the Marine Consents Unit and the Northern Ireland Department for Environment respectively.

These above regulations as applicable for England and Wales are illustrated in Figure 22 below.

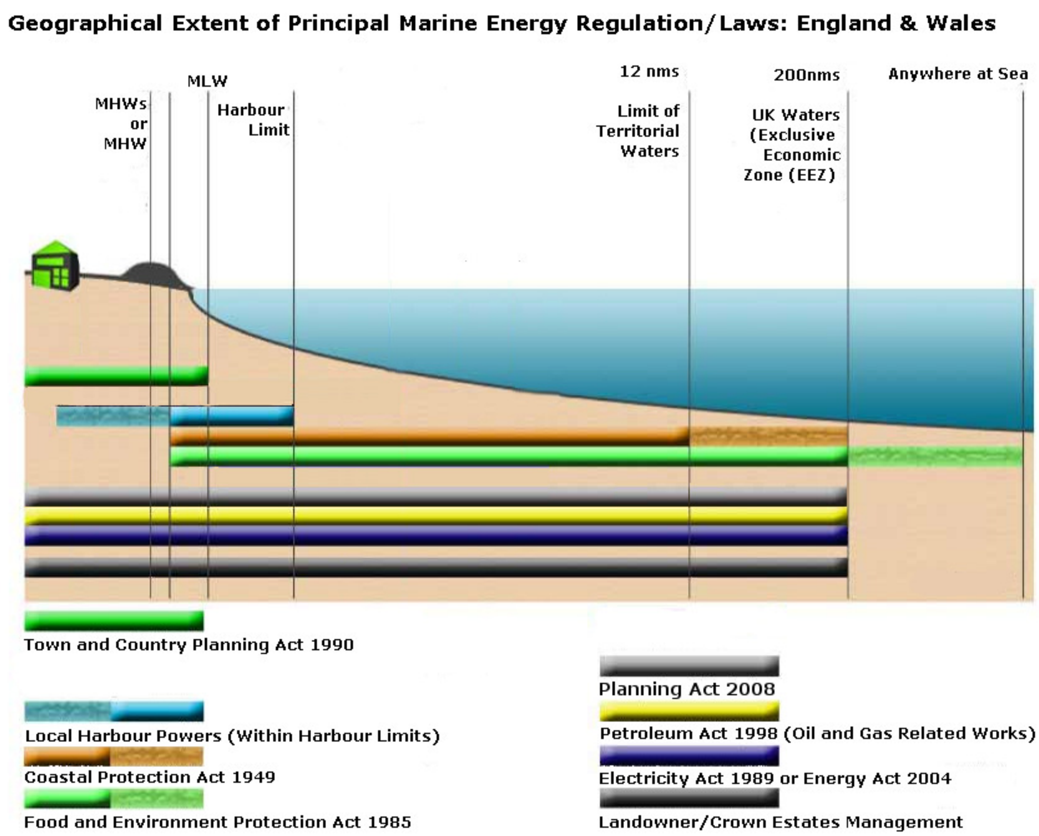


Figure 22: English and Welsh Marine Regulatory Regime

3.3.5 Electrical Grids and Regimes

The UK's electricity regime can be broken into two specific areas: firstly, regulations regarding connectivity and operation of the electricity network itself (e.g. H&S, grid operational parity etc.). The second area covers the regulations and procedures relating to the sale and supply of electricity as a commodity within the electricity market.

3.3.5a Electrical Connectivity and Operation

The main electrical regulation applying to the development of marine renewable energy projects is the Electricity Act 1989 Section 36 consents. Within operation and as part of the transmission licence agreement of the EA89, projects must adhere to a set of codes (known as the Grid Code) that include correct frequency (as well as phase), voltage and power factors within a designated tolerance. In addition to this, generators must supply forecast demand data for the Balancing and Settlement Code (See Sale and Supply of Electricity section below) as well as historical annual generation data. In addition to section 36 of the EA89, Section 37 relate to the installation of overhead cables which may be required within the onshore construction element.

3.3.5b Sale and Supply of Electricity

Sale and supply of electricity is facilitated by thousands of generators, suppliers and intermediaries. There are two primary agents however responsible for the management of this interaction and ensuring that the system functions according to design these are the National Grid as system operator and the not-for-profit settlement company, Elexon who are the Balancing and Settlement Code (BSC) administrators.

Electricity in Britain is traded in half hour 'slots' of delivery called 'Settlement Periods' though the British Electricity Transmission and Trading Arrangements structure (BETTA). Through BETTA, power purchase agreements are often signed months or even years in advance between electricity generators and supplier companies (e.g. the 'big six' suppliers).

Electricity can be sold and bought in advance of generation (or 'delivery') up until one hour before hand. From this moment, a mechanism known as 'balancing' takes place. Since electricity is a non-storable commodity and predictions for both demand and supply of electricity can be inaccurate, National Grid authority and responsibility for buying or selling (at a premium) any imbalance within the supply/delivery before the transmission period.

During transmission, imbalances can also occur if a generator fails to provide the contacted generation or again, if demand un-expectantly peaks, in which case 'spinning reserve' (contracted generators who are on standby ready to produce extra generation immediately) are used to fill the demand gap.

After the half hour of transmission, Elexon, the BSC administrators, analyse who transmitted what and (according to their contracted supply) fines those that failed to provide what was contracted. This BETTA mechanism is shown in Figure 23 below.

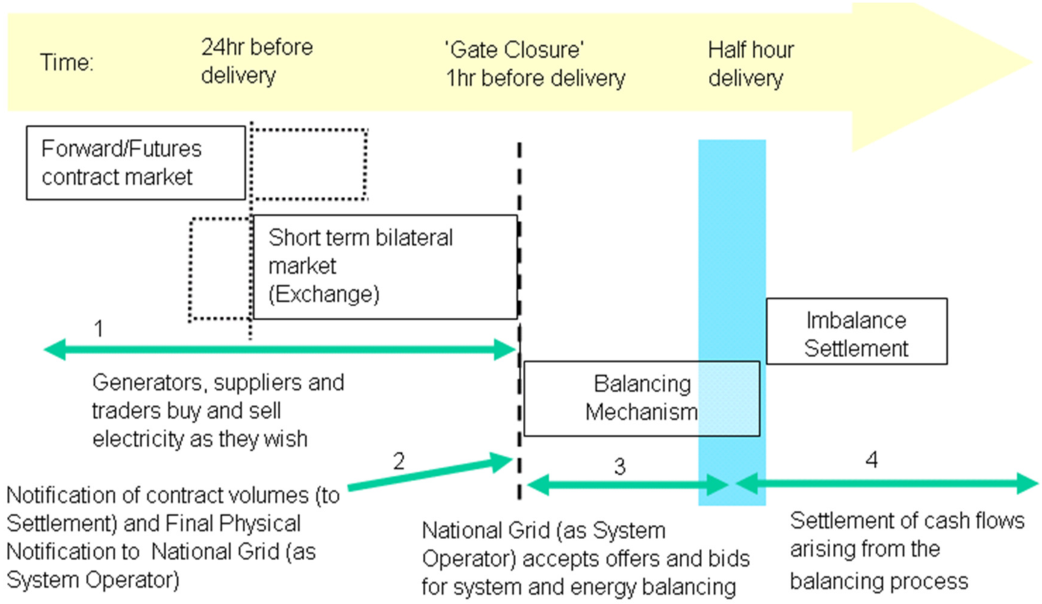


Figure 23: BETTA Structure (National Grid Electricity Transmission plc, 2011)

It has been widely noted currently that the BETTA structure, although having a legacy of providing for cheap end user electricity, has biased against intermittent generation (specifically wind whereby generation prediction is not as available as it is with coal/gas or nuclear) and failed to promote low carbon weighting within the balancing mechanism. Additionally, it has failed to promote both investments in extra (and replacement) capacity as well as the grid upgrading required (Energy and Climate Change Committee, 2011). As such, the system is currently under review with varying proposals in consultation and a replacement mechanism yet to be announced.

3.4 Conclusive Remarks

This chapter has provided a background review to the system under analysis. Along with the Literature Review (Chapter 2) this chapter has provided the background of understanding required for the research undertaking to now be addressed more directly and within context. This is now discussed directly within the next chapter, (the Research Question) which shall set out the overall goals of the research to be undertaken and thus the direction of work within the rest of this thesis.

4. The Research Question

Table of Figures:

4.1 Chapter Introduction

This chapter provides the primary research questions for which the methodology is established. The order by which the questions are outlined bears no significance on their importance. A brief insight into the overall methodological approach is also provided however this is very rudimentary and greater detail can of course be found within Chapter 5, the Methodology.

4.2 The Research Questions

In innovation theory, the concept of the Technological Innovation System, (TIS) has been developed and refined by a range of academics, however was fully developed and presented as a tool of analysis by Bergek *et al*. in 2008. (Carlsson and Stankiewicz, 1991, Jacobsson and Johnson, 2000, Liu and White, 2001, Oltander and Perez, 2005, Bergek *et al.*, 2008a).

Although this model does not address wider societal aspects such as 'regimes' of normative, regulative and cognitive rules (as identified by Geels (Geels, 2004)), it does pay credence to the social landscape through two specific functions: 'Legitimacy' which encompasses social acceptance and compliance with relevant institutions and the 'Development of Positive Externalities' which focuses among other things upon inter-industry relationships and capital such as labour markets, knowledge spillovers and intermediate goods and services (Bergek *et al.*, 2008a). Functionality is further explained within the literature review (section 2.3.3g) but in essence the functionalities within a system can be thought of as the variously defined conceptual processes that occur (such as the creation of knowledge or the formation of markets) which in turn aid or impede the overall dynamic evolution and 'health' of a system.

TIS analysis has the considerable advantage of practicable *applicability* that is strikingly missing from many other systems of evaluation and wider 'society inclusive' methodologies. It's logical 'step-by-step' approach to evaluation and identifiable measures of system performance allows for a more replicable and thus more confident deconstructive analysis and understanding of innovation systems from which policy decisions can be made.

As mentioned however within the introduction section (1.3.1), many of the current measures of innovation used both within systems analysis and innovation research more broadly, rely on codifiable and quantifiable outputs (such as patents and publications) to measure innovation but fall short on providing insight into the creation of informal innovation factors such as the creation of social capital, collaborative interactions non-patented innovations and the creation of norms and practices. Additionally, when perceiving innovation as a community guided activity (be it collaborative research, through supply chains etc.), innovation indicators fail to peer inside what Rosenberg first described as the 'black-box' of innovation (Rosenberg, 1982).

The advantage therefore of the TIS approach could be capitalised on further if stronger measures of informal innovation and other less codifiable systemic achievements could be included within the analysis of an early stage system's functionality. This leads to the first of the research questions within this thesis which is:

How can we come to a clearer understanding of early stage technological innovation systems through robust and transferable measures of key emergent system functionalities?

A clearer understanding of which policy instruments have what affect on which functionality, in the context of a particular social milieu will not only increase efficacy but also allow for an increased accuracy of monitoring and resolution of functionality performance. The question then emerges as to whether this increased confidence and insight into system operation can allow us to conduct benchmarking comparisons between spatially or socially different emerging sub-groups (such as countries or technologies), thus helping to provide a higher level of efficacy to applied policy support. Efficacy in this context can be defined as the effectiveness of any chosen government support policy in achieving its goals, be it increased industrial development or labour within the system, higher levels of technology diffusion or faster levels of technology cost reduction per unit of cost or time, (depending upon the objective of the policy.)

When looking at existing TIS theory, we must assess the method's existing level of *operationalisability* before attempting to implement alternative forms of system functional analysis. Having asked what potential methodologies are currently available for analysing emergent TISs, (including both 'status-quo' methodological approaches as outlined by Bergek et al. and 'novel' approaches) for analysing emergent system functionalities at this early stage of technological and industrial sector maturity, we can now raise the second of our research questions:

How insightful are the various methodologies for system functionality analysis, how replicable are they, (therefore how well do they strengthen the overall robustness of the system analysis)?

Finally, through looking at the value of our system's functionality indicators we can ask the research question:

What can TIS analysis tell us about the current status of the emerging wave energy sector, what are the current problems and opportunities that policy makers can attempt to mitigate or capitalize on?

There will unfortunately be externally complicating restrictions on this approach to systemic analysis. In the early stages of the system's evolution, exogenous factors may dominate until the system evolves and expands out of its incubated niche status and has developed strong enough internal functionalities to withstand or adapt to outside influences (Bergek *et al.*, 2008b). How it brings these external factors under control and within the sphere of systemic influence is part of the formation process and understanding this, we can ensure that external factors are recognised as beyond policy control (in respect to the system as well as its advocates) and not mistakenly viewed as endogenous to system formation.

4.3 A Brief Overview of Methodology

In answering these above questions, the focus of research within this thesis is therefore on harnessing a stronger and more comprehensive understanding of the emerging wave energy industry and its associated technologies to help assist in its development from 'niche' market status towards a fully commercial state of maturity.

As mentioned above, work on technological innovation systems, (notably by Bergek et al. 2008) has identified that the successful development of certain key processes (functionalities) have been present within successful innovation systems, (i.e. ones that have progressed to a stage of industrial maturity and economic 'independence' from incubated or niche funding). It is also clearly identified by Bergek that different functional activities should and will be present at different stages of technology maturity. For example, finding a low level of technology diffusion in an emerging system is not evidence of system failure since one would not expect this to occur until other processes (such as increased legitimacy and reduction of uncertainties) have occurred. It is therefore believed that through assessment of these functions it may be possible to both identify problem areas of sectoral growth and build stronger normative policies that will help to develop and sustain emerging sectors through the various stages of industrial maturity.

The primary method used to provide insight into the dynamic interactions occurring at this stage of sector maturity is the application of social network analysis, the application of which may allow for assessment of: industry and technology field intra-relationships, 'clustering' (i.e. level of disbursement of actors within the industry or technology field); centrality (i.e. identification of actors with proportionally higher strong links to other actors, which can be thought of as an indicator of 'prime mover' status); and overall 'robustness' of the system (i.e. business field proximity of actors and strength of relations among them).

An example of network analysis in application could be identification of levels of cooperation between academia and private industry within the wave energy sector, something that has been highlighted in previous studies as a weakness within the sector (Renewables Advisory Board, 2008). Although it would not be possible to assess the levels of interaction on its own, comparison can be made between interactions of different stakeholder types (e.g. between device developers and other firms or government bodies), different countries (e.g. between Scottish device developer/university interaction and English device developer/university interactions) and indeed on an individual scale for comparison (e.g. between different device developers of different levels of technical maturity).

Another approach to this investigation is a qualitative analysis based on information gained through interviews, questionnaires and media related sources. This plays as large a role within the research methodology adopted here as it would in any existing TIS analysis.

Finally, a phasic form of assessment known as technology readiness levels shall be applied as a process of identifying the stages of technical maturity for individual device developers creating an overall impression of both the market 'leading' technologies and the overall paradigm in which the sector is situated (Poole *et al.*, 2000, Mankin, 1995).

Providing a reference valuation of 'successfulness' of a sector in which the future outcome of the technology and industry itself is not yet known provides a further methodological problem. If for example the sector does not manage to mature past a certain point before public funding was withdrawn, the technology may never reach a stage economically competitive, against incumbent technologies within the renewable energy sector. In this scenario, the benefits of the sector would most likely neither repay the initial public funding invested into it nor sufficiently mitigate levels of carbon emissions necessary to justify its funding. The crux of diagnostic understanding when presented with this scenario however would be whether the *technology* failed (i.e. our ultimate lack of engineering capabilities and knowledge) or the *system* failed (i.e. poor support measures, knowledge diffusion, industrial environment etc...)

In this scenario, the answer to this question cannot be answered without conducting comparative assessments.

What can be assessed is the *relative* successfulness of one nation over another. Although the field of technology is the same, (wave energy, despite its many technical variations) the levels of system 'success' at a national level may differ dramatically (as outlined earlier and based on indicators such as deployment capacity and economic contribution). Through comparative evaluation of more than one county's policies, (i.e. England and Scotland) it may be possible to draw conclusions as to which present a better system environment into which the technology could emerge. Figure 24 below shows how this assessment could be made.

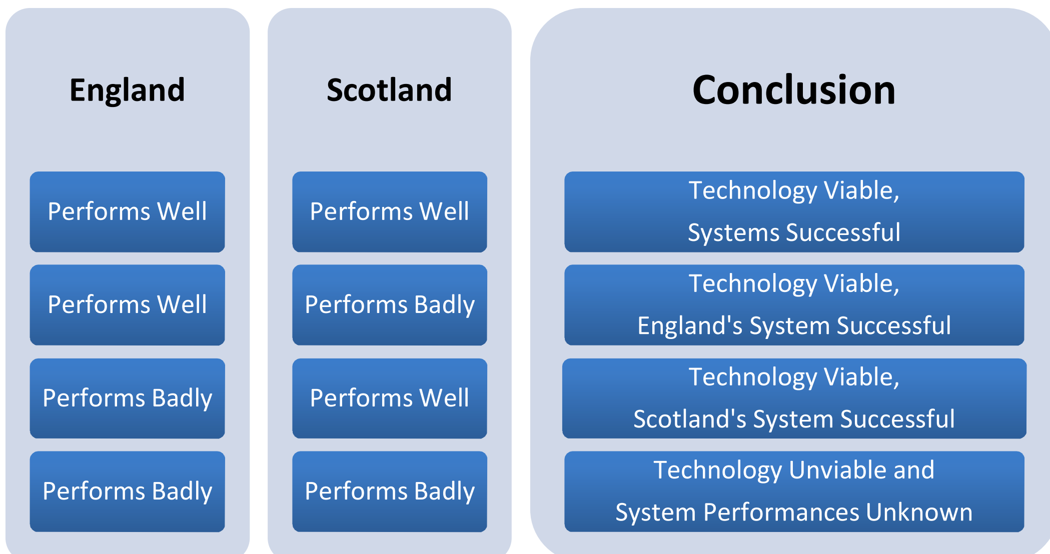


Figure 24: System Performance Assessment Matrix

England and Scotland make a good 'test' division since Scotland has a devolved administration (the Scottish Government), that provide not only independent support policies for renewable energy technology but also innovation, skills and employment. In addition, Scotland has a clear and strongly articulated ambition to become a forerunner within the commercialisation of the technology (BBC, 2008). It would therefore seem logical that their functional achievements/health and thus systemic performance/output would be greater than that within England.

Although this does not provide insight should both support systems fail, the most feasible output of this investigation would be that one system would at least perform differently from the other (regardless of whether either system succeeds or not). What could then be examined is the efficacy of each countries policy (to promote deployment for example) against the actual development of the sector within that country.

To operationalise the research, interviews shall be conducted with all key stakeholders within the sector, data gathered, processed and analysed in such a way as to answer the above questions. This process shall be discussed further in Chapter 5, the Research Methodology.

The hypothesis behind this research is firstly that, until a level of saturation (described below), there will be a present and strong correlation between levels of centrality that an actor has and their contribution towards systemic growth through other measurable proxies (patents/publications/technology readiness levels etc.). This would be expected to increase until a point before network saturation at which time the effects of both geometrically increasing redundancy constraints and arithmetically increasing transaction costs (both of which occur between network actors) result in an optimised level of network exposure for an individual actor.

The underlying network assumptions of this work are that at this emerging and problem solving state of sector development, network entrepreneurs are those that have a higher network horizon and work through network brokerage (bringing in the resources/capabilities of 'non-system' actors) and exploitation of network holes. Collectivised problem solving however is done through tighter, problem solving networks (Low and Abrahamson, 1997)(see SNA within innovation studies section 2.4.4 of Chapter 2, the Literature Review for more on this). Therefore, although some network actors will attempt to work strategically within the structure of the network (i.e. through entrepreneurial brokerage or by exploiting network prominence within a sub group such as universities to acquire further funding or influence upon system formation), most actors work egocentrically with a simple network horizon of one (Anderson *et al.*, 1994).

Through these various approaches as well as a comprehensive understanding of the current literature on industrial development, energy policy, innovation theory and diffusion theory, primary data can be collected and manipulated, (through network analysis, qualitative analysis etc...) to shed light upon the processes and their interactions using Bergek's TIS model. Thus relative levels of functionality obtained.

Once a picture of causal functionality relationship is created and assessed, it is hoped that through comparative evaluation between different regions, (i.e. Scotland and England) and sub groups (i.e. companies and universities) bottle-necks to both deployment and industrial growth can be identified.

It is also believed that both failing and successful support policies for industrial development could be identified and thus recommendations provided on ways to increase the overall efficacy of funding (and thus ‘value-for-money’ of public investment). Additionally, it is intended that more effective non-financial support measures could be suggested that would maximise the sectors chances of innovation, industrial development and overall economic success.

4.4 Conclusive Remarks

This chapter has set out the primary research goals within this thesis and very broadly, the methodology by which these research goals shall be met. The following chapter (the Methodology Chapter) now discusses the more intricate detailing of how this research was undertaken and aims to address the novel methodologies used which were drawn from a synthesis of theories addressed within the Literature Review (Chapter 2). This methodology is then employed to produce the finding and analysis chapters (6 and 7) which are then used to inform the final discussion chapter ((9 and 10).

5. Methodology

Table of Figures:

Table of Tables:

5.1 Chapter Introduction

This chapter details the methodology by which the primary research of this thesis was undertaken. Primarily this is done through two main processes of data collection; desktop research and key stakeholder interviews. The findings themselves were then analysed through two processes: Firstly, within the framework of the TIS using status-quo metrics and secondly, through the application of network analysis. All of these methods of analysis were framed under the functionality approach of Technical Innovation Systems (TIS), (described within the Literature Review, Functionality (section 2.3.3g). Finally, these functionality findings were synthesised into the later stages of the 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).

5.2 Defining the Technological Innovation System

This research examines the potential for applying TIS analysis to the wave energy sector. In existing theory of TIS analysis, the first stage was to define the innovation system under investigation. As outlined by Bergek et al (Bergek *et al.*, 2008a) various choices had to be made at the initial stages of the system analysis that were fundamental to the overall process of analysis as they defined the way in which the analysis was conducted, and also to some degree, the value of the analysis itself. The wrong choice of system boundary within the definition stage of the analysis would have greatly affected both the validity and applicability of the overall results. Bergek outlines three key dimensions that must be consciously defined at the outset of an innovation systems analysis. These are identified as follows:

1: *The product and knowledge field*. This field is fairly self explanatory, in that it refers either to a particular technology type, (i.e. wave energy converters) or a knowledge field (i.e. the conversion of energy from waves). It does not specify the scale and dimension of analysis but rather the focus of attention, be it artefact based or knowledge field based. This choice may not be very clearly distinguishable within certain fields where the artefact embeds much of the knowledge of the sector however in heavily regulated or integrated sectors, where knowledge of the *context* in which the artefact is placed is important, it becomes clear that there is indeed a distinction between product and the knowledge field.

2: *The choice of breadth or depth of analysis must be decided*. Within breadth and depth are two parameters outlined by Bergek et al: Level of aggregation and range of application. The level of aggregation refers to the detail of the analysis. One could for example look at wave energy devices from several levels of aggregation. As a component part within 'Wet Renewable Technologies', 'Renewable Energy Technologies' or event 'Environmental Technologies' in which the depth of investigation would no doubt be more limited unless the resources underpinning the overall investigation were scaled proportionally to the task. Alternatively, one could define the analysis in terms more specific than the wave energy sector such as, 'Deep Sea Offshore Wave Energy Converters' or 'Point Absorbing Wave Energy Devices' or various other combination in which the level of detail within the analysis would be much greater however the understanding of the greater 'landscape' or 'regime' (Geels, 2004, Berkhout *et al.*, 2003) in which the innovation is situated would be much more limited. This can be shown within the tree diagram, Figure 25 below:

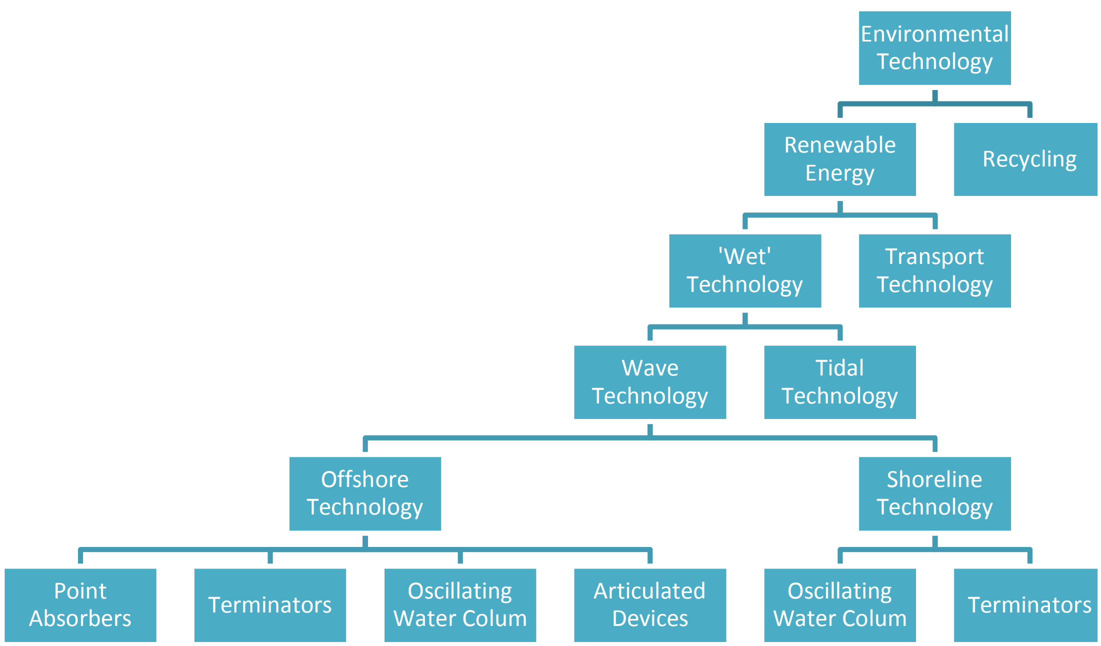


Figure 25: Example Tree Diagram of 'System' Aggregation

3: *The breadth of applications available for the innovation*. Although this is not particularly relevant for wave energy devices since their range of applications are limited, one could suggest, ‘Wave Energy Converters for Island Application’ over ‘Wave Energy Converters for Larger Grid Integration’ or ‘Desalinating Wave Energy Devices’ over ‘Electricity Generating Wave Energy Devices’. Despite the latter example having a different physical construction process, the selection distinction is appropriate as the scale of application are the same, (i.e. the physical devices).

Ultimately, making these choices always requires something of a trade-off between the level of resource and time available to the researcher as well as the value gained from increasing the dimensions of analysis which must reflect the overall ambition of the study being undertaken. An analysis should be as large and coarse as is needed to be so that the level of external factors influencing or affecting the system (i.e. system externalities) are seen to be low enough to render the analysis valid, yet the detail must be high enough so that important functional nuances and components of the system which could have an effect on functionality performance are not missed.

For this research, the analysis of the innovation system focused on wave energy technology devices specifically. By this it is meant that any devices used for converting the motion of the waves, (whether swell or immediate fetch wind generated) into either an electrical output, or into mechanical motion that can be used to pump fluid or desalinate water. This included all types of installation location from onshore design types, (such as Voith Hydro’s Limpet wave energy device) as well as offshore devices (such as Pelamis Wave Power’s Pelamis wave energy device). Various publications have defined the scale and type of the many different wave energy devices present (see Chapter 3, Background Review of the Sector section 3.3.2e and 3.3.2f for a more expanded review of devices), however for clarity of analysis, this research examined all European Patent Classification (EPC) codes under the sub heading F03B13/14. These are defined under: ‘MACHINES OR ENGINES FOR LIQUIDS > Adaptations of machines or engines for special use; Combinations of machines or engines with driving or driven apparatus characterised by using wave energy’ (European Patent Office, 2010). A copy of this classification and its subsequent sub-categories can be found within Chapter 3, the Background Review of the Sector, section 3.3.2e.

Although it is clear that similar technologies and knowledge fields (such as offshore wind and tidal energy as well as the oil and gas sector) have an impact on the sector from both a technology and skills/labour ‘spillover’ benefit, these influences are captured in the ‘development of positive externalities’ functionality measure and were specifically excluded from the core research technology and system boundary since the benefits of their inclusion are heavily outweighed by the practical research limitations of the study.

5.3 Identifying Actors, Networks and Institutions

The second stage of network analysis is that of component identification. One of the differences between the standard TIS model of analysis (as described within the Literature Review) and the alternative TIS model outlined here is that the identification of functioning 'networks' as individual 'components' within the system can be fully assumed once defined (i.e. identified by any actor) whereas it's functional value (for differing functions in contributing to the overall health of the system) is monitored and critiqued within the alternative analysis. Likewise, levels of value and crossover between multiple networks is also assessed.

The key focus of the alternative TIS analysis however hinged upon actors and their interactions. In order to get a complete and clear understanding of the system, it was important while identifying actors/agents, to have a clear definition presented as to who represented a member of the innovation system under investigation and in what capacity. This identification needed to be defined to ensure that methods for actor identification did not extend outside of the scope of study and result in an eventual analysis of data that did not represent the focal demographic which has a stake within the system. This process was in effect an expansion of the first stage presented within the TIS analysis methodology outlined by Bergek *et al*. as 'Defining the TIS in focus' (Bergek *et al.*, 2008a), Since, however the variant system analysis to be conducted had to have a defined analytical focus on each individual agent, (used within the SNA analysis) a clear boundary to the system needed to be drawn and the classification of actor roles imposed.

Within the study of the innovation system, the system boundaries were set at a level which could both answer the initial research questions and realistically be examined to provide insightful feedback of the system itself. As a result of this requirement, a distinction was drawn between those agents who provided inputs/outputs to the wave energy innovation system, (exogenous actors) and those who were core to the functionality and growth of the system itself, (endogenous actors). While there is clearly an argument for an 'over-inclusive' analysis to be adopted over an 'under-inclusive' one, the resources available, (in terms of man-hours of research, funding etc.) constrained the selection process to a conservative optimum.

One of the key differences between the standard TIS model of innovation and the research conducted here was the geographical boundary of the system under analysis. Bergek states clearly that; "an analysis always needs to have a strong international component simply because a spatially limited part of a global TIS can neither be understood, nor assessed, without a thorough understanding of the global context" (Bergek *et al.*, 2008a). There was however a strong rationale for not adopting this international focus within the TIS analysis conducted within this research. The main reasons for this are two-fold:

Firstly, since an 'individual actor' analysis level of resolution was required within the alternative TIS, the methodology prohibited the practicality of such a wide scope of assessment within the initial iteration of study. However, although the primary alternative analysis began with an 'assumed' key actor identification (as outlined below), the analysis process itself identified those most relevant (and irrelevant) actors both nationally and internationally for secondary iterations of analysis and beyond. These actors could therefore be included and excluded from future analysis based upon their contribution to the system functionality alone rather than simply their geography.

This leads to the second reason for a national spatial boundary of analysis which is born from the first. If innovation systems are as we assumed to be 'dynamic' and worthy of multiple iterations of analysis, the question then presents itself; what is a valid starting point of analysis? As suggested above, the system boundary would be one in which the exogenous components are such as to have minimal influence upon the internal dynamic of the system thus being wide enough to absorb many of the factors that influence its formation. In this respect, a national boundary for this analysis for the wave energy sector is validated for several strong empirical reasons. These factors include:

- The strong elements of national government and national heritage (language, culture, education) (Lundvall, 1988).
- Other factor conditions affecting the sector which have a national dimensions including the natural resource (i.e. the UK coastal waters or exclusive economic zone), the national electrical grid and its institutions of operation (i.e. effectively a large 'isolated' island grid).
- The many regulatory and legal institutions that are clearly national in nature (e.g. for, electricity, renewable energy, planning, health and safety, marine operation laws etc.).
- The long historical pedigree on wave energy research that has been not only nationally focussed but has also created a very strong national pedigree and established group of actors (see Background Review of the Sector chapter 3 section 3.3).

- Finally, due to the clearly nursing stage of the market at this time, the sector is almost entirely grant-supported and thus growth is dictated by a national R&D agenda and support subsidy.

Many of these national aspects are outlined by advocates of technological innovation systems as being validating reasons for a national boundary of analysis (Liu and White, 2001, Carlsson and Stankiewicz, 1991). Once the market expands into a forming/ demonstration/ pre-supported market stage and convergence as well as diffusion of technology occurs, these national boundaries will become less valid as international markets of product diffusion begin to play a stronger role.

When identifying the system (and non-system) actors, the intent was to analyse them under a set of groupings, (such as academic, marine bodies, etc.) and thus create a finer resolution of understanding with regard to the functional roles played by heterogeneous agents who were both endogenous and exogenous to the system. This in turn allowed for a focused analysis on the system actors while still enabling us to factor in the inputs/outputs from exogenous actors to the system while undertaking a network analysis.

Classifications of actor type have been broken down into the following main categories:

- Final Device Developers: All companies that design and manufacture wave energy devices including those at early stages of device development including design and modelling phases (i.e. all TRL stages).
- Other Companies: All stakeholder companies working within the wave energy that are not identified by any other classification within this list.
- Utility Companies: Primarily the ‘big six’ utility companies however other smaller and international utility companies working specifically within the wave energy sector were also included.
- Central Government Departments: Both national and devolved central government departments as well as central government departments of other countries such as DECC, the Scottish Executive or HM Treasury. As with other actors, system inclusion was based on primary involvement within the wave energy sector.
- Other Public Sector Departments: Include European, national and regional public bodies as well as renewable energy specific support bodies. This category also included NDPBs who have a key role within the sector.
- Universities and Research Bodies: Includes all academic institutions active in wave energy research, and similar industry research bodies.

- Test Centres: Specifically this related to the three key UK wave energy test centres which are clearly heavily involved within the sectors development.
- Collaborative Networks: Related to all networks that hold a stake in the wave energy sector and was inclusive of public stakeholder groups, renewable energy specific stakeholder groups, marine utility stakeholder groups and others that were identified. Although these networks may be collaborations of other agents, this was identified at the network analysis stage and helped to include network 'peripheral' stakeholders such as Surfers Against Sewage for example who have an important voice within the sectors development but were not identified through an individual actor identification method.

These actor types were chosen on the basis of the triple helix theory of innovation model outlined by Leydesdorff (See section 2.3.5a of the Literature Review, Chapter 2 for further details) (Leydesdorff, 2000). Universities, test centres and device developers represent an innovative element, trade associations and especially utility companies represent the market force and government agencies represent the 'control' element of the helix.

To assure full identification and inclusion of actors within the sector who fulfil this criteria were identified, a classical chain referral method of snowballing identification (Goodman, 1961) was used until saturation was met. When an actor who was not a member of the core sample demographic was identified, the actor was added to the analysis as an agent from which knowledge is gained. However, other than their actor identity, classification (within the above taxonomy), geographical location (nationally), and relationship to the referee; they played no further role within the snowballing. Therefore, if for example, a key actor such as a device developer identified an engineering consultancy company as their main source of knowledge, the named company was added to the network analysis as a source of technical knowledge for the device development company; their classification and national location were obtained however the consultant company was not interviewed and no further information about the consultant company was obtained. If however, the device developer identifies a university or government department as a source of technical knowledge, the referenced agent was added to the 'snowball' process (unless they fall out of the geographic boundaries of the study, in which case they were added to the network but not the snowball as with other exogenous actors).

It has been shown that this chain referral 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) and thus provides an effective methodology, especially when seeking full saturation of the network such as was the case within this study.

To ensure that a high proportion of the network was covered once the primary research was conducted, the number of non-respondent primary system actors was identified and the 'value' of their interaction (i.e. the summated value of interaction as referenced by system actors as outlined further below) was assessed against the overall levels of interaction reported. In this way, if there was a large level of non-respondent system actor interaction occurring (in comparison to that internally identified between system actors and between system and identified non-system actors) then it would have clearly show up as a low level of system actor representation and vice-versa.

Since the survey sought full saturation within the network, the principal snowballing seeds did not need to be randomly selected. To reach the highest level of saturation, a large initial list of actors were selected whom it was thought would hold a strong level of knowledge integration within the sector. As the focus of the study is itself was upon the wave energy sector and its development (with a particular focus towards the specific entrepreneurial locus of innovation within the network), *all* UK based wave energy device developers made up the part of the initial seed of the study. By definition, these developers are (unless defunct) valid system actors. Device developers and other initial informants were identified using:

Waveplam State of the Art Analysis report, (Waveplam, 2009).
EMEC Wave Energy Developers list, (European Marine Energy Centre, 2009b)
UKERC Energy Research Landscape: Marine Energy Sector (Mueller, 2009)

Within the above actor classification list, all UK actors other than those classified as 'other companies' *actively involved* within the wave energy sector were included within the analysis (i.e. HM Treasury was referenced however as they were not actively funding projects (rather than through DECC for example) they were excluded from the analysis).

The initial sample of actors contacted in the first round of interviews is listed below as well as their relevant actor taxonomy code:

Companies:	Category:
Aquamarine Power	Final Device Developer
AWS Ocean Energy Ltd	Final Device Developer
Checkmate SeaEnergy	Final Device Developer
C-wave Ltd	Final Device Developer
Dartmouth Wave Energy Limited	Final Device Developer
Embley Energy	Final Device Developer
FreeFlow 69 Ltd	Final Device Developer
Green Cat Renewables Ltd	Final Device Developer
Green Ocean Energy	Final Device Developer
Lancaster University Renewable Energy Group	Final Device Developer
Manchester Bobber Company Ltd	Final Device Developer
Neptune Renewable Energy	Final Device Developer
Ocean Navitas Ltd	Final Device Developer
Ocean WaveMaster Ltd	Final Device Developer
Offshore Wave Energy Ltd	Final Device Developer
Pelamis Wave Power Ltd	Final Device Developer
Pure Marine Gen Ltd	Final Device Developer
Scotrenewables (Marine Power) Ltd	Final Device Developer
Trident Energy Ltd	Final Device Developer
Voith Hydro Wavegen Limited	Final Device Developer
British Gas	Utility Company
E.ON	Utility Company
EDF Energy	Utility Company
RWE Npower	Utility Company
Scottish and Southern Energy	Utility Company
Scottish Power	Utility Company

Public Sector Bodies:	Category:
Department for Energy and Climate Change	Central Government Department
Scottish Executive	Central Government Department
Welsh Assembly	Central Government Department
Crown Estates	Other Public Sector Department
Ofgem	Other Public Sector Department
Marine Managemnt Organisation	Other Public Sector Department
Carbon Trust	Other Public Sector Department

Research Bodies:	Category:
University of Exeter	University or Research Institute
Durham University	University or Research Institute
Hariot Watt University	University or Research Institute
Imperial College London	University or Research Institute
Lancaster University	University or Research Institute
Northumbria University	University or Research Institute
Queens University Belfast	University or Research Institute
Southampton University	University or Research Institute
University of Edinburgh	University or Research Institute
University of Manchester	University or Research Institute
University of Oxford	University or Research Institute
University of Plymouth	University or Research Institute
University of St Andrews	University or Research Institute
University of Strathclyde	University or Research Institute
Energy Technology Institute	University or Research Institute

Test Centres:	Category:
Narec	Test Centre
EMEC	Test Centre
Wave Hub	Test Centre

Collaborative Affiliations:	Category:
RenewablesUK (Form. BWEA)	Collaborative Affiliations

Table 6: Initial Actor Survey List

5.4 Conduct Primary Research

There are two separate stages to the primary research phase of the analysis. The first is a desk-based research into the background data while the second stage is an interview process to ascertain many of the core metrics within both the established TIS measures as well as those required within the network analysis. Interviewees were asked a series of questions which were set to draw out the information required to conduct both the 'established method' of analysis using conventional measures as highlighted in the below section (5.5.1), and also to obtain information required to undertake the alternative TIS analysis helping create, among other things, a multi-layer social network analysis of the sector (SNA allowing for the alternative TIS indicator method to be applied.) This means that the interviewing process for both forms of systems analysis was done using the snowballing technique since interviewees were only identified through the referral process (starting with the ‘first-wave’ as outlined in the previous section).

The questions (included in Appendix 1.0 of this chapter) were presented to the interviewee in order to obtain the relevant information needed for the completion of both the standard and alternative TIS analysis however a ‘flexible dialogue’ within the interview process allowed interviewees to give a narrative responses to more open ended questions.

For all stages of the primary data gathering, there was a hierarchy of evidence gathering that was to be followed. The overall outcome goal of the study is to establish the ‘health’ (in terms of its current and future expectations of market growth and maturation as well as the more detailed identification of bottlenecks, threats and opportunities) of the wave energy sector using the innovation systems analysis. For this, the functionalities had to themselves be assessed and relative levels of ‘goodness’ assigned, however functionalities were themselves clearly non-measurable directly, (e.g. there is no direct quantifiable measure of ‘market formation’ for example.) As such, proxy indicators were used to infer the health of the functionality, (e.g. an assessment of the levels of employment would be a proxy indicator for the resource mobilisation). In many cases these proxy indicators were as far as the theory goes and some degree of inductive understanding of the system under investigation was implied upon the researcher for this to be deduced. In the description of the data gathering process below however, detailing of the raw data itself, as well as the source of raw data, is stated, so as to make explicit exactly what steps were carried out within the primary data gathering process of the study. To summarise, Figure 26 below shows a depiction of the ‘hierarchy of research steps’ undertaken. This pyramid of analysis is clearly wider at the base since the raw data (e.g. number full time and part time of graduates within different disciplines at each institution) was compiled into fewer proxy indicators (e.g. FTE graduates within different knowledge fields). These proxy indicators were in turn are compiled to assess the health of specific functionalities (e.g. a low number of FTE graduates would add weight to the argument that there is a poorly functioning ‘Knowledge Generation’ function within the sector). Finally, an overview of functionalities within the sector overall enabled an assessment of overall health (as defined above).

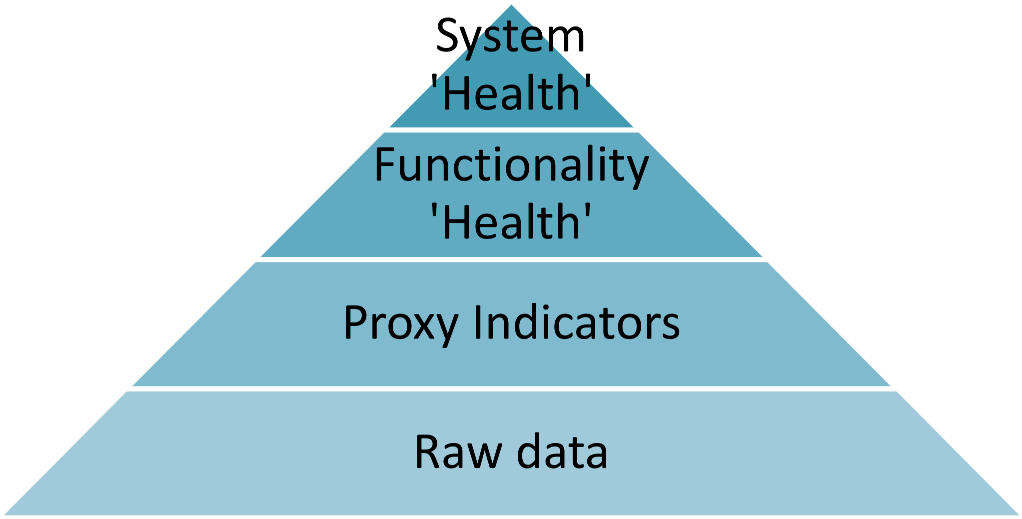


Figure 26: Hierarchy of research steps

5.5 Established TIS Analysis Research

The initial *analytical* step undertaken was be to assess the wave energy sector by country (and where relevant by stakeholder type) using the existing TIS indicators as outlined in the literature by Bergek et al. (Bergek *et al.*, 2008a). Using this methodology, the following functionalities were assessed using measures as given below however the detailing of data manipulation (i.e. from raw data to proxy indicators etc.) is provided within the findings itself.

5.5.1 Functionalities and Measures of TIS analysis from existing theory

5.5.1a Resource Mobilisation

Resource mobilisation refers to both fiscal resource mobilisation and labour resource mobilisation. Since all financing has to date been spent on R&D and there is yet to be any significant level of deployment, R&D project spend is sufficiently accurate to reflect all public spending upon the sector to date. To assess this, a time series of public spending within the sector was identified using desktop based identification of publications on the financing of the wave energy sector including:

Entec UK Ltd, (for BWEA): Marine Renewable Energy State of the industry report – October 2009 (Entec UK Ltd, 2009).

IEA Online Energy Database. (IEA, 2010)

IEA-OES: Review and analysis of ocean energy systems development and supporting policies (IEA-OES, 2006).

Mueller: UKERC Energy Research Landscape Marine Renewable Energy (Mueller, 2009).

POST: Marine Renewables (POST, 2009).

RAB: Marine renewables: current status and implications for R&D funding and the Marine Renewables Deployment Fund (Renewables Advisory Board, 2008).

Along with various other sources such as press releases etc... Although this did not allow for analysis of private finance, investment statements from the larger supply companies as well as personal interviewing was used to gain an insight into projects that were privately financed by these companies.

Additionally to the amount of R&D spent or earmarked for the sector, the conditionality of access was examined as this has important implications for developers depending upon their level of technical maturity.

The second indicator; labour resource mobilisation was measured by obtaining statistics from sector specific publications (within the desktop study). Additionally, all interviewees were asked what their levels of full time equivalent (FTE) employment rate is working within the wave energy sector of their organisation and from this, calculations as to the FTE workers within the sector overall, (through extrapolation) was derived.

Other indicators assessed within this function were the number of postgraduate students that interviewee (universities) report to have as well as the expected skills and educational requirements that are required for the sector.

5.5.1b Influence of the Direction of Search

Primarily, this function tries to obtain an understanding as to what factors influenced actors into entering into and engaging with the wave energy market.

The many influencing factors were broken down into three primary sub-divisions:

Externalised influence upon the direction of search

Internal influence upon the direction of search

Investor influence upon the direction of search

The externalised influence upon the direction of search translates into the motivating factor for non-system actors into entering into the market. This includes, government and other key stakeholder publicised growth targets and deployment expectations (such as roadmaps) and how these brake-down geographically or technically. As such, all key central government departments were asked what there deployment expectations for the sector are by 2020 and 2050. Additionally, desk-based studies were conducted to assess published capacity estimations.

Internally, the influence on the direction of search is presented twofold: Firstly, as the device developers' own expectations of deployment (i.e. effectively their externalised influence upon expectation) which was then compared with other expectations of externalised influence, (i.e. government expectations). Secondly, through asking stakeholders what influenced them into entering into the sector a historic picture of influence within the sector was then created. Answers were classified into motivating factors for different actor types and countries (i.e. England, Scotland, Wales and Northern Ireland.)

Finally, as key stakeholders within the sector, investor research conducted by Kreab & Gavin Anderson was examined to determine (in conjunction with primary data gathered from the Legitimacy section of the research explained in section 5.5.1e) what factors influenced (or have deterred) investors into entering into the sector (Walter, 2010).

5.5.1c Materialisation

This functionality indicator was straightforward in that it required measures of both capacity deployment to date and device developer progress towards commercialisation.

The first of these factors; current deployment is the most clear indication as to the level of absolute 'achievement' within the sector however it does not indicate the level of progress that the current milieu of developers have achieved. To assess this, (as an indicator of a company's level of device maturity) the EMEC 'Pathway to EMEC' list (European Marine Energy Centre, 2008) was extended on to include small arrays, the relative level of technology maturity was included as outlined in Foxon's technology maturity curve (Foxon *et al.*, 2005) and this was aligned with the technology readiness levels defined by NASA (Mankin, 1995). Companies were asked to specify the level to which their devices had been developed providing for a more detailed assessment of technological maturity and materialisation. From here, a ‘ranking’ of device materialisation was made using the results. The technological maturity classification can be seen below in Table 7.

	Step Descriptions:	Step Location:	#
R&D:	**Applied & Strategic Research**		
	Basic principles observed and reported	Concept for a Wave or Tidal Energy Converter	1
	Technology concept and/or application formulated	Concept for a Wave or Tidal Energy Converter	2
	Analytical and experimental critical function and/or characteristic proof of concept	Utilise Research Providers (Universities etc.)	3
	Component and/or partial system validation in a laboratory environment	Develop Design Utilising Engineering Expertise	4
	Technology Validation		
	Component and/or partial system validation in a relevant environment	Tank Testing	5
	System/subsystem model validation in a relevant environment	Scale Test Facilities e.g. NaREC	6
Demonstration:	**System Validation**		
	System prototype demonstration in an operational environment	Full Scale Test Facilities - EMEC	7
	Actual system completed and service qualified through test and demonstration	Full Scale Test Facilities - EMEC	8
	Actual system proven through successful mission operation	Full Scale Test Facilities - EMEC	9
Pre-Commercial:	**Commercial Validation**		
	Singular system 'commercially' deployed on successful long term grid connected installation	Pre-Commercial Deployment - EMEC/Wave Hub	10
	Small arrays (<10MW or 20 devices) 'commercially' deployed on successful long term grid connected installation	Pre-Commercial Deployment - Wave Hub/Pentland Firth	11

Table 7: Technology Maturity Classification for Wave Energy Devices (Adapted from NASA TRL (Mankin, 1995))

5.5.1d Knowledge Generation/Diffusion

Knowledge generation and diffusion is seen as one of the crucial functionalities within any emerging TIS, to monitor this function Bergek suggests the use of several techniques: R&D investment, patents, learning curves and bibliometrics (Bergek *et al.*, 2008a).

The first of these, R&D project/investment over time was assessed under the Resource Mobilisation section (5.5.1a) as almost all current spend within the sector has been on R&D.

Patent analysis was conducted in a threefold manner. Firstly, through an overview of patents both nationally (including a historic analysis of patenting) and internationally, (to provide context for the UK research status) held by the European Patent Office website (espacenet.com), for patents conforming to the classifications for wave energy devices shown in the EPO classification section (3.3.2e) of the Background Review of the Sector. Additionally, a filter was placed to ensure that they are published within Great Britain, (e.g. 'GB' prefix on publication search). Once obtained, patent group lists were created according to technology categories. Secondly, patents figures were obtained through the primary interview stage directly asking device developers, universities, test centres and utility companies how many wave energy sector related patents they hold. Finally, amongst this same set of interviewees, both the reason for their patenting as well as the perceived value of patenting was asked to obtain a system perspective the value and use of patents within the sector.

Experience curves within the technology were also obtained from several key publications to show the level of cost reduction that is expected with an increased deployment within the sector. There is however currently a high level of uncertainty within these expectations due to the low level of data on deployment costs to date. These publications included:

- BWEA: Pathway to Power (British Wind Energy Agency, 2006).
- Carbon Trust: Future marine Energy (Carbon Trust, 2006).
- Entec UK Ltd, (for BWEA): Marine Renewable Energy State of the industry report – October 2009 (Entec UK Ltd, 2009).
- Garrad Hassan: Development of Wave Energy in the South West (Garrad Hassan, 2008).
- RAB: Marine renewables: current status and implications for R&D funding and the Marine Renewables Deployment Fund (Renewables Advisory Board, 2008).

Finally, a bibliometric study was conducted to assess the level of relevant wave energy sector publications produced and available. Specifically, Web of Knowledge, EBSCO and Science Direct were examined using a keyword search for "Wave Energy" or "Marine Energy". The citations for these results was then downloaded (into Endnote) and filtered for both overlaps and relevance (through .csv exportation into Excel). This produced a list of paper publications (over time) within the sector. To compliment this methodology, all university/research centres were asked how many publications they have had (within the past 3 years for practicality of response) relating to wave energy technology and within three core knowledge themes, (technical, environmental/planning, market and fiscal knowledge). Finally, all interviewees were asked what they perceive to be the value of academic work as a knowledge contributor towards the sector.

5.5.1e Legitimacy

Although strongly qualitative in nature, legitimacy is both perceived and created by varying sub-groups of both the sector itself and larger groupings within society such as the general public and potential investors. DECC's: historic Renewable Energy Awareness and Attitudes Research reports was used to assess the changing levels of public recognition and favour of wave energy technology sub divided by different nationalities (GfK NOP Social Research, 2009, GfK NOP Social Research, 2008, GfK NOP Social Research, 2007, GfK NOP Social Research, 2006).

One of the key stakeholder groups with influence over the perceptions of legitimacy for the wave energy sector however are central government departments (GfK NOP Social Research, 2009). Additionally, as a primary funder for the sectors development, government representation of sectoral legitimacy indicates both the current political value of the technology and the expected future funding landscape. A qualitative assessment therefore of the different governments' perceptions of the technology was undertaken using key policy statements, government roadmaps and other strategy documents published by central government bodies. In line with this, all interviewees were asked what they believe to be the dominant future wave energy market (in terms of both manufacturing and deployment) out of both England and Wales (which are collated due to their identical support regime as of the time of data gathering) or Scotland.

Following on from this, the investor perception of legitimacy provides a strong indicator into what private finance can be leveraged into the sector. To assess this perception a twofold strategy was used. Firstly through a desktop study of publications related to investor confidence (specifically the Kraeb Gavin Anderson study into investor confidence (Walter, 2010)) and secondly, through the primary interview stage, utility companies (as key investors) were asked which (if any) wave energy technologies they are currently investing in and what they perceived to be the long term valuation of the wave energy sector to their business.

The internal perceptions of legitimacy were examined with a finer resolution of legitimacy on the different technology sub-groups (non-fixed, semi/fixed, OWC and overtoppers). This was done through the direct questionnaires; asking stakeholders what they perceived as the most promising technology category in development. Since device developers undoubtedly hold a strong bias and central government departments attempt to be inherently technology neutral (whether this is or not factually the case), these stakeholders were not asked this specific question.

5.5.1f Market Formation

One of the primary indicators assessed within this field was the number of established wave energy focussed stakeholder networks that are currently present within the UK. Through assessing the size, membership profiles, funding profiles and mandates of these networks, an impression of what current activities are being collectively resolved and represented within the sector was created. For example, a large customer network would show that investors are aligning themselves to represent their collectivised interests whereas a large number of environmental deployment networks would show that there is a communal need to overcome current uncertainties within the planning and environmental aspects of the sector.

One of the key indicators of market formation is the assessment of the type of market. Bergek suggests assessing the market in one of three phases; nursing, bridging or mature. There are however different terminologies for this market progression (such as Low & Abrahamson's slightly dissimilar; 'Emerging, Growth and Mature' definitions)(Low and Abrahamson, 1997). For the wave energy sector the technological uncertainty, lack of deployment and low stakeholder and customer numbers show that the market is quite clearly in the earliest stage, that of 'nursing'. This level of market development agrees with the technology development stage of wave energy which in Foxon's technology maturity curve (Foxon *et al.*, 2005), places wave energy clearly in the early R&D/Development phase.

With this in mind, the market formation function can be assumed to be at an underdeveloped stage of formation (although this is not the same as dysfunctional), however, as suggested by Bergek, key customer statements on the technology were sought and during the main customer interviews, companies were asked about their belief in the potential for wave energy technology, what the wave energy sector needs to be seen as attractive from an investment perspective and what their company is doing to help accelerate the commercialisation of the sector.

5.5.1g Development of Positive Externalities

As functionalities, indicators for the level of development are possibly the most elusive ones to find despite there being a great deal of importance placed on the aspect of this function and its successful 'operation' (Bergek *et al.*, 2008a, Bergek *et al.*, 2008b). Bergek suggests various proxy indicators for assessing the development of positive externalities however the operationalising and acquirement of this knowledge is left patchy and tacit meaning that robust indicators were not easy to acquire.

A qualitative assessment of related industries (such as the oil and gas industry and wind industry) and their own specific impact upon the overall different functionalities within the sector was conducted to identify the many influential affects that these industries have had upon the sector.

Some suggested identifiers for the development of positive externalities include: The emergence of specialised intermediate goods, which are unlikely to be prevalent within the wave energy sector (although this is more likely to be due to the infancy of the sector and the uncertainty of the nature of these goods, (e.g. crew transfer vessels etc.) than the nature of the technology.)

Secondly, the emergence of pooled labour markets is considered as an indicator, as with the mobilisation of resources, the number of graduates/post-graduates passing through the university educational system was compared with the total number of employees considered to be directly employed by the system as a whole (through the qualitative interview process). Although this leaves a clear gap in complementary employment services, (such as consultancy services, component manufacturers etc, it at least provided an overview of the employment 'through-put' of the system and thus how much human resource is in scarcity or excess therein.

5.5.1h Entrepreneurial Experimentation

Through the questionnaire process, all interviewees were asked about their company history including both when they registered as a company (for solely wave energy related companies) or when they moved into the wave energy sector for universities and other stakeholders. This assisted in the creation of for a 'time-line' of entrants into the wave energy sector.

A further indicator for the amount of entrepreneurial experimentation that is occurring within the sector includes the number and arrangement of test centres available within the UK. A brief review of these stakeholder assets was conducted to assess their contribution and value (in terms of the number and length of device testing that has occurred at them).

Desktop identification of the number of wave energy device developers currently in operation within both the UK (done through the initial stakeholder identification) and globally shall be conducted to assess the diversity of developers within a wider context (i.e. roughly assessing international competition).

“Experiments undertaken” is also noted as an indicator for entrepreneurial experimentation. For this indicator, device developers, test centres and universities with test tanks were asked how many hours of tank test time had been undertaken for devices specifically, (not just components) and which devices had been tested.

5.5.2 Established Functionality Metrics Summary

In summation, the functionality indicators for the above established measures (or proxy indicators) is given in the below Table 8.

Established TIS Functionality Proxy Indicators		
Function	Proxy Indicator	Raw Data
Resource Mobilisation	Fiscal Resource	Fiscal resource estimates from various publications/statements assessed
	Human Resource	Employment estimates from various publications/statements assessed
		All stakeholders asked for staff numbers within market, tech and environmental fields
		All universities asked for numbers of graduates within market, tech and environmental fields
Influence of the Direction of Search	Government Influence	Published deployment expectations and roadmaps assessed
		Levels of subsidy provided assessed
	Internal Influence	Device developers asked for their deployment expectations of 2020 & 2050
		Stakeholders asked what influenced them into entering into the sector
	Investor Influence	Taken from Kreab Gavin Anderson report ((Kreab Gavin Anderson, 2010)
Materialisation	Levels of Deployment	UK deployment from both published data on deployment and through directly asking device developers assessed
		Device developers asked about their devices level of technology readiness level (TRL)
Knowledge Generation/ Diffusion	Patent Generation	Database searched (EPO) for all related patents submitted by stakeholders
		Stakeholders asked patent number, values and justifications
	Learning Curves	Obtained from various publications/statements
	Bibliometrics	Journal databases searched for publications
		Stakeholders asked for number of publication within different knowledge fields
	R&D Expenditure	Refer to fiscal resource mobilisation statistics

Established TIS Functionality Proxy Indicators		
Function	Proxy Indicator	Raw Data
Legitimacy	Public Perception of Legitimacy	DECC (Dti) Renewable Energy Awareness and Attitudes Report assessed
	Government Representation of Legitimacy	Public sector policy statements assessed
	Investor Perception of Legitimacy	Obtained from various publications/statements
		Utility companies asked for their future expectations of the technology
	Internal Perception of Legitimacy	Stakeholders (except device developers) asked on their expectations for different technology groups
	Legitimacy of the Technology	Standards, certifications and practices available to legitimise technology assessed
Market Formation	Maturity of Market	Evident nursing market (From low levels of materialisation/tech deployment)
	Formation of Networks	Number, profile and mandate of established marine/wave energy networks assessed
	Drivers' to Market	Stakeholders asked on their perception of investor barriers
Development of Positive Externalities	Functionalities' Relations Across Sectors	Functionality spillovers from related sectors assessed
	Other Established Indicators	Intermediate goods assessed (very low levels of emergence)
		Politically supportive power assessed
		Emergence of pooled labour markets assessed (very low levels of emergence)
Entrepreneurial Experimentation	Profile of Sector Entrants	All stakeholders asked when they entered into the sector
	Diversification Activity	Number of wave energy actors within the UK and internationally assessed
	Experiments Undertaken	Device developers, universities and test centres asked how many hours tank test time they have conducted

Table 8: Established Status-Quo TIS Functionality Indicators

5.6 Alternative TIS Analysis Research

5.6.1 Intro of TIS Measures for Alternative TIS Analysis

In parallel with the data gathering process for the established TIS functionality indicator analysis, further primary data was obtained to help assist with the alternative system functionality analysis. All of the original functionality proxy indicators are used for the alternative analysis however certain functionalities were effectively added to with the application of Social Network Analysis helping to strengthen the overall system analysis by providing additional information and analytical tools for the completion of the functionality analysis as well as providing other feedback on the nature of the system at large as outlined below.

> "Identifying how transfers of knowledge and technology take place, what the main sources of knowledge and technology flows are for enterprises, and which of these are of greatest importance is central to understanding linkages in the innovation process. They result in better understanding of diffusion process and make it possible to map linkages and knowledge flows, and they are of direct relevance for innovation policy."
>
> (OECD, 2005)

The overarching approach to the inclusion of SNA in the technological innovation systems analysis is twofold: Firstly, through directly questioning all stakeholders within the system where they source their knowledge from, and secondly, through the application of SNA on patents covering the wave energy sector registered within the UK.

The first and by far the largest element (using SNA within the qualitative interviews), involved the identification of a large initial seed of actors who were then (through a snowball referral process described below) used to identify secondary, tertiary and further waves of network actors. This process of identification and selection of system actors and the initial seed of actors is described in much greater detail within section 5.3 Identification of Actors, Networks and Institutions.

Throughout the process of snowballing, interviewees were asked where they obtain their knowledge in terms of three distinct categories of knowledge that are described below:

- Technical Knowledge: This pertains to all technical knowledge needed in construction of a wave energy converter including; structural, electrical, mooring and mechanical knowledge. (N.B. Technical knowledge does not extend to field of knowledge that are not directly related to wave energy technology such as onshore substation works etc.)

- Market and Fiscal Knowledge: Including all elements of project costs and revenues, other company related fiscal opportunities and threats and knowledge of wider economic activities affecting the sector.
- Environmental, Planning and Regulatory Knowledge. This field relates closely to knowledge of 'institutions' in the systems analysis perspective. That is, knowledge of the varying regulations, laws, licensing and constraints under which the wave energy sector operates.

It is acknowledged that these fields are not wholly independent and that many specific knowledge elements overlap such as wave resource prediction which clearly relates to both the economics of a project and the operating conditions in which the device will be placed, (i.e. survivability and reliability issues).

Stakeholders were asked who they were or have been interacting with over the past three years and asked to place this interaction into one or more of the above categories. They were then asked to value the level of knowledge that they receive from that interaction according to a valuation of between 1 and 10 with 1 being a very minor level of knowledge interaction and 10 being a crucial and strong level of interaction and knowledge transference. The primary goal of using this data as a proxy for knowledge received was also explained to them so as to clarify the metric. Interviewees were allowed to name as many references as they wished as outlined within the snowball-sampling technique described within the start of this chapter.

Although this value mechanism (an 'individual measure' of relations, (Hanneman and Riddle, 2005)) appears at first somewhat arbitrary, it has several advantages over other valuation methods of rating interaction value. These are:

- Unlike a simple binary relationship, (i.e. 'who did you receive information from') a valuation level allowed for analysis of the strength of ties between agents rather than just the presence of a tie and thus provided more insight (i.e. 'how much did you receive from…')
- Although differing agents may value the same knowledge differently, the very nature of knowledge and the opportunity which it provides to different actors means that it has a subjective value relative to the receiver. If for example, one were to ask, "value your knowledge exchange according to a monetary equivalent," then different stakeholders would, not only value the same piece of information differently, but also place an economic value based on their

own subjective valuation of money, (i.e. some stakeholders may have higher reserves and consider money in easier supply than others.) Therefore, placing a fiscal metric creates an error margin based on the valuation of the stakeholder's perception of their surplus capital.

The goal of this extended questioning was to create a multi-dimensional epistemic network for the different types of relevant knowledge flow within the wave energy sector. Once the interview process was completed, the different relations were entered into the Ucinet database and SNA metrics of analysis conducted (as described under the different extended functionality sub-headings below).

The second, indirect source of knowledge network gathering was operationalised by using the patent classification grouping used within the standard analysis and filtered so that patent categories (according to EPC codes) were analysed using Ucinet SNA software (again as described below). The SNA patent network included those patents specifically cited within each patent application itself as separate nodes so that those patents most cited could be identified (as having a higher level of reference, and thus 'in ties' indicating the level of influence which the patent has had).

The full analysis to be conducted is shown within the individual extended functionality indicator section below.

5.6.2 Functionalities and Measures of TIS analysis from extended theory

5.6.2a Influence on the Direction of Search

This alternative functionality analysis pertains less to the external luring factors which motivated individual companies into entering into the sector or technology group (as described by Bergek). Instead it sought to identify what technology influences are driving the sector's internal search heuristics from within the system, thus influencing those actors who are already engaged within the sector.

It is understood (and discussed within Chapter 2, the Literature Review) that within network analysis, actors with a high level of 'out centrality' (i.e. actors who many others have referenced) are referred to as 'influential' (Hanneman and Riddle, 2005). Although this is true within the context of purely social networks, since ties within this epistemic network represent knowledge flow rather than simply 'communication', these metrics are considered to be more appropriately assessed within the knowledge generation and diffusion section (2.6.2b) of this chapter. It is however acknowledged that this provision and supply of knowledge *will* affect the search heuristics within the sector and thus the functional overlap should be noted: The acquisition of knowledge an actor reports to acquire from his/her alter and the level of influence that this therefore has upon them would seems intuitively correlated. Instead therefore of assessing influences of actors, this work analysed the internal influence of artefacts through patent analysis.

Effectively, this is akin to the influence of what Dosi describes as the supply side, 'technology push' heuristics which influence the overall technological trajectory within the system (i.e. acknowledged breakthroughs in or recognition of successful technology)(Dosi, 1993). In application, there are various measures of patent influence that could be applied. When patents are applied for, applicants must cite all relevant patents that have had a specific influence upon the patent design. As a result of this, a chronological 'family tree' of patent influence was created following citations back through references. Once this network was created, analysis was conducted through two groups of measures: The first measures were individual patent heuristics which were examined through different measures of centrality, namely degrees centrality (and local degrees centrality), betweenness centrality and (due to the binary nature of the relationships) harmonic closeness centrality. These individual measures gave levels of influence for both the immediate patent proximity (in terms of the amount of direct influence provided by patents) as well as overall network levels of influence (in terms of the 'legacy' of the patent's overall influence upon the sector since the latter measures of closeness asses the geodesic distance to all other patents). More detailing of these measures can be found both within the Literature Review chapter (2.4.2) and Chapter 7, in the Additional Findings and Calculations, Influence upon the Direction of Search (section 7.2). The second group of measures applied was from the higher perspective of group influences and can be thought of as the levels of influence that certain patent families (e.g. overtoppers) have had upon the search heuristics within the patenting community. This was explored through the average levels of group citation, super-node analysis (i.e. assessing the absolute number of references per sub group between sub groups) and direct group centrality (i.e. how much of the overall network has been influenced by each patent family).

5.6.2b Knowledge Generation/Diffusion

Unlike the established methodology for analysis of knowledge generation and diffusion, the alternative approach looked at individual agents and assessed the knowledge diffusion levels from a systems perspective through the analysis of the SNA epistemic networks maps for the three different knowledge types (technical, market/fiscal and environmental/planning).

One thing that network analysis cannot provide (even for an epistemic network) is a clear measure of how much knowledge any single actor/sub-group is *generating*, since this is an output of the actor/sub-group that may not be related to the relationships which it possesses, (i.e. is qualified through the building of competences, outputs of patents/bibliometrics etc.) Although it is well known that there is a strong correlation within high technology networks between knowledge creation and collaborative networks (see for example (OECD, 2005, Shan *et al.*, 1994)), simply assessing the number of knowledge relations an actor has does not quantify how much knowledge they are generating, but rather, how much knowledge they are *diffusing* or *receiving*.

The key process therefore for examining the knowledge diffusion within the sector therefore was to assess the out-degrees of individual and groups of actors, identifying those who are 'steering' the sector research heuristics by contributing most to its overall knowledge generation. These are the 'prime movers' who have a strong influence on, and can influence not only the technological search heuristics but also affect the legitimacy of varying technology sub-groups (Jacobsson and Johnson, 2000). Having a high level of 'out degrees' (i.e. being referenced by many stakeholders as a source of interaction and knowledge) equates to having a high level of knowledge diffusion, whereas having a high level of 'in-degrees' of knowledge can be thought of as a measure of overall knowledge reception.

Working with the different epistemic networks, the overall levels of cumulative knowledge flows within different knowledge types was identified, and sub-categorised, (i.e. how many university/industry collaborations are occurring, how many company tank tests are occurring etc…) both for the entire system and for the England/Scotland systems. Additionally, to straightforward measures of 'how much' knowledge value was being diffused within the sector, information on the structure of knowledge flows was gained using SNA tools such as network cohesion as well as analysis on different sub-groups within the network. As noted within the literature review, theories on network optimisation for innovation conflict suggest, closed/dense networks are thought to be most beneficial from a network perspective (see section 2.4.4 for more details) for problem solving high technology sectors.

Looking at innovation output, (whether this is from a device developer, university or other agent), theorists believe that having not only strong ties to alters (those that an actor is engaged with) is beneficial, (i.e. strong knowledge flows to and from alters) but also having strong ties *between* alters assists in facilitating knowledge diffusion. In this theory, network ‘closure’ (i.e. being highly clustered around your alters) helps to reinforce your (ego’s) level of innovation (Coleman, 1988, Walker *et al.*, 1997). This could be operationalised by identifying the overall cohesion of the different knowledge networks.

One of the indicating factors of a firm’s innovative influence relates to its overall network position. Here, the number of collaborative relationships formed between it and other actors within the system has been shown to positively relate to its levels of innovation output (Shan *et al.*, 1994). As such, one of the indicators used was to assess the level of collaborative ties held by device developers specifically and compare agents/patent statistics and levels of device maturity to validate if there was a direct correlation.

5.6.2c Market Formation

Market formation could easily be thought of as the subset of metrics (inclusiveness, average tie density, clique analysis etc.) applied to the market/fiscal knowledge network. This assessment however would fail to appreciate the value of non-commercial knowledge (such as the technical foundations of intellectual property and competence as well as the physical environment and its management) that sit as a plinth under which market decisions, opportunities and threats are made. As such, although it could rightly be suggested that the market/knowledge relationships represent the most tangible expression of market formation, the creation of *all* knowledge networks into a functioning ‘topology’ (whatever this may look like) was assessed as a representation of the current market structure with observations made accordingly (e.g. there are many technically isolated device developers and large environmentally consultancies dominate the environmental/planning networks).

The first measure to be applied therefore was that of inclusiveness. Inclusiveness simply defines the number of isolates within the network however, assessing this over both the different knowledge fields as well as the different system actor types (i.e. system/non-system actors etc.) validated the system boundary chosen. A high value of system actor inclusiveness within the different knowledge networks would show that there is a high *diversity* of interaction occurring between system actors (in terms of knowledge types) whereas a low level of inclusiveness would show low levels of multiplexity (i.e. highly specialised knowledge fields) among system actors. This logic also applies to non-system actors and it would be expected that, as peripheral agents to the system, these actors would be more specialised and thus have lower inclusiveness.

The next measure of applicability is the average tie value. For directed and weighted networks such as that created within the study, average tie value is the exact same thing as the network density however, since the network includes non-system actors, this measure alone would give a misleadingly low average tie value (since non-system actors do not have the option to refer). As such, two measures for average non-tie value were used:

Firstly, the average non-zero tie value for different knowledge types (and between different actor types) between system actors and other system/non system and all network actors was assessed. This provided a reference as to whether system actors have on average stronger relations with other system actors or not within the different knowledge field types and therefore help validate both the system actor boundary as well as providing fundamental insight into the structure of the network (e.g. most system actors gain access to market/fiscal knowledge from other system actors but seek technical knowledge from non-system actors etc.)

Secondly, the network data was manipulated to make assessments of absolute density (i.e. average tie strength inclusive of absent values) so as to assess between different sub-groups such as the density measures of different nationalities and stakeholder types as well as the average measures *between* different sub groups. This provided information on how cohesive these sub-groups are (e.g. universities may have a dense technically collaborative network whereas device developers may have a relatively sparse market/fiscal network due to commercial sensitivity). It also allowed for an assessment of where different sub-groups gain the predominance of their information (e.g. device developers gain a high level of technical knowledge from universities or Scotland receives low levels of market knowledge from England). To make these assessments however the data required manipulating to account for non-respondents and as a result, the network was made reciprocal between all system actor>non system actor relationships for this analysis (i.e. it is assumed that if a device developer is reporting an environmental interaction with a non-system actor, the relationship is reciprocated to the same strength). Additionally, since there is bi-directionality within the network, averaged values of relationship were provided between two reported relationships.

An N-Clique analysis was used as a further assessment of network formation to assess the levels of triadic clustering occurring within the different knowledge fields and stakeholder groups (see the Literature Review, Chapter 2 for a more in-depth explanation of clique analysis (2.4.2e)). Since the n-clique analysis is only possible for binary data sets, this provided an opportunity for further insight as differing levels of dichotomy were assessed to examine the effect on the clique analysis within these data sets. If for example, a heavily dichotomised data set was applied (such as only relations of 9 and above for example), then only the most intensive knowledge cliques would be shown however if a low level of dichotomy was applied then (in comparison with the high dichotomies assessments), a wider assessment of all intensities of clique structure would be provided. As a result of this, an assessment of the structure of the different sub-group networks was assessed in terms of their clique values (e.g. a high average number of strong technical cliques within universities would represent a very cohesive technical research structure within academia or; despite its individually influential actors, Scotland only has a relatively low level of strong national clustering).

The final analytical tool available that can be thought of as a market formation indicator is that of homophily. Homophily, (as explained further within Chapter 2, Literature Review (2.4.3a)) is a measure of the level of inter to intra sub group interaction or; how likely it is that actors of the same group are likely to interact with other actors of the same group. From this measure, it could be found for example that technical interactions tend to occur nationally rather than internationally or that in summation, different stakeholder types tend to interact with each other more than with stakeholders of their own type. Although this is not as relevant to market formation, it does provide a useful piece of quantitative information regarding the overall network structure that could help policy makers determine whether high levels of inter-organisational group interactions (for example) are occurring.

5.6.2d Development of Positive Externalities

The primary indicator available for this functionality within the alternative measures has the advantage of being far more quantifiable/codifiable then is the case with the standard analysis. Bearing in mind that the functionality of positive externality refers to the spillover of knowledge/resources/capital/time etc. *from* other close proximity systems *to* the system in question, the study is therefore looking at what extra knowledge is being bought into and under the control of the system in question (Bergek *et al.*, 2008a, Bergek *et al.*, 2008b). This was to measure the amount of knowledge *inflows* from non-system actors compared to the amount of internal knowledge flow occurring within the system, (i.e. large inflows of technical knowledge from wind industry actors or the hydraulics industry will show spillovers occurring from these sectors into the wave energy converter sector). Effectively, this measure can be expressed for the system actors or sub-groups as:

$$K_{spillover} = \frac{\sum_{1}^{n} k_{in}}{\sum_{1}^{n} k_{internal}}$$

Where:

$K_{spillover}$ = the sum knowledge spillover
k_{in}= the knowledge input to the network
$k_{internal}$= the overall level of internal knowledge occurring

This spillover indicator was refined to show which type of external actors are providing the most information and roughly how that breakdown occurs, (e.g. many non-system public sector departments are providing very high levels of environmental and planning knowledge).

Ideally, actor identification for political 'power struggles' could be assessed using SNA and in depth analysis of the debate and power struggles for each 'campaign' (such as MCAB and ROC banding) could be done however this would be a very resource intensive amount of work for the outcome on its own and is therefore considered to be beyond the scope of this study.

5.6.2e Entrepreneurial Experimentation

The definition of entrepreneurs within the social science field of SNA is rather different from that of evolutionary economics. Within SNA fields, entrepreneurship relates more to a distinct social positioning within the network in which they are embedded whereby actors, (or more specifically, nodes), who have a high level of 'brokerage' power over other nodes within the network can be categorised as differing types of entrepreneur. Unfortunately, the theoretical assumptions of entrepreneurial brokerage used within SNA make the (rational) assumption that group membership/identification when applying entrepreneurial brokerage measures influence the appropriateness of members to interact with other groups, (i.e. there is some level of validation as to why different group members may not interact such as group rivalry, physical locality or social acceptability) (Gould and Fernandez, 1989a). Since this is not the case within this study, (i.e. there are no reasons for why different countries/sub-groups cannot interact), brokerage measures prove inappropriate.

Another similar ego-based measure however that was applied to entrepreneurial experimentation is a measure of structural holes as outlined by Burt (Burt, 1992). Although less directly associated with entrepreneurship, the two metrics of network efficiency and constraint provided by Burt represent the extent to which a node's (or stakeholder's in this case) relations know each other or not and how much overlap there is between each alter and one's own alters. This can therefore be used to assess the levels of redundancy that an actor has between his own alters, (i.e. if he can be easily circumvented by his alters or if indeed he can circumvent alters should he chose to). This is explained further within the Chapter 2, the Literature Review section 2.4.4a.

5.6.2f Alternative Functionality Metrics Summary

Functionality indicators for the alternative proxy indicators are given in the below Table 9.

Additional TIS Functionality Proxy Indicators		
Function	Proxy Indicator	Raw Data
Influence of the Direction of Search	Technology Search Heuristics	Patent group influences assessed through supernode analysis
		Patent group centrality scores assessed
		Individual technology centrality scores assessed (for most influential patents)
Knowledge Generation/ Diffusion	Individual Stakeholder Diffusion	Stakeholder degree centralities for different knowledge fields assessed
		Stakeholder harmonic closeness centralities for different knowledge fields assessed
		Stakeholder betweeness centralities for different knowledge fields assessed
		Individual cohesion density and average tie scores for all knowledge fields assessed
	Sub Group Knowledge Diffusion	National levels of centrality scores for all knowledge flows assessed
		Stakeholder type centrality scores for all knowledge flows assessed
		Established network centrality scores for all knowledge flows assessed
	Full Network Knowledge Diffusion	Full network density scores for different fields assessed
Market Formation	Assess Internal Market Development	Inclusiveness scores for all knowledge flows assessed
		Network density/average ties for all sub groups and for all knowledge flows assessed
	Formation of Cliques	Network n-cliques for all sub groups and for all knowledge flows assessed
	Homophily of Actors	Homophily of actors within network for all sub groups and for all knowledge flows assessed
Development of Positive Externalities	External In-flows to the System	Knowledge inflows from non system actor sub groups into all knowledge flows assessed
Entrepreneurial Experimentation	Effective Size and Constraint of Actors	Structural hole metrics for all actors and for all knowledge flows assessed

Table 9: Alternative TIS Functionality Indicators

Technical detail:

All software Ucinet measurements were taken using UCINET 6.344 Copyright (c) 1992-2011 Analytic Technologies. Unless otherwise stated, default settings were applied as provided within Ucinet.

5.7 Methodological Discussion

The methodological discussion is an external element to the wave energy sector innovation systems analysis itself and assesses the actual insight, applicability and limitations of the metrics used as well as any methodological findings resulting in the analysis undertaken, (i.e. conceptual understandings of the theory that may be drawn out from the process of analysis). It shall be sub-divided into two sections, one assessing the established metrics and the other, the SNA metrics as described below.

5.7.1 Established Metrics Findings

The discussion on the established metrics presented the insights, challenges and limitations found when applying the established metric indicators to the sector. Since the methodology followed is described within this chapter, the established metrics discussion highlights where this process came across problems, (and how these were overcome) as well as an assessment on whether the metrics themselves either provided valuable information or proved to be less insightful. This critique should of course be taken within context of both the sector type itself and the specific characteristics, (such as maturity of the sector etc.) which may have a strong bearing on the validity of the metrics used. This section therefore does not simply suggest ‘which metrics are good and which are bad’ but is rather a critique of how applicable they were within the context of both the system under analysis and the methodology used to acquire them.

5.7.2 Social Network Analysis Metrics Findings

This section discussed the applicability, limitations and insights from the application of network analysis to the system. Unlike the established metrics however, the SNA metrics are 'unique' in that they have never been applied within the context of this form of analysis, and therefore there is a wider scope for critique of application since they provided both unexpected insights and likewise, unexpected problems in operationalising and interpretation.

Both the established metrics discussion and the social network metrics discussion were assessed both as an overview, (i.e. data collection and applicability issues) as well as in reference to their applicability to each system function.

5.8 System Analysis and Discussion

The system analysis and discussion section completed the innovation systems analysis through the synthesis of all functionality indicator findings provided within the previous chapters. The format of this chapter was be split into two broader sections; assessing the functionality of the TIS as well as identifying blocking mechanisms (effectively, the 'positive' economic assessment) and secondly, a policy recommendation section which highlights specific recommendations to policy makers for trying to assist in the overarching goal of commercialising the sector (effectively the 'normative' economic assessment).

5.8.1 Assessing the functionality of the TIS & Identifying Blocking Mechanisms

As identified by Bergek, one of the historic problems of systems analysis comes when trying to identify what constitutes a well operating, or well functioning system. To overcome this, Bergek suggests both assessing the phase of development of the sector and comparative analysis with other systems (to obtain something of a relative measure of which systems are performing in comparison to others) (Bergek *et al.*, 2008a). The first of these suggestions is straightforward, since the sector is clearly identified as a nursing/emerging stage of development and as such, it was assessed with expectations as such, (i.e. high levels of risk and uncertainty, low levels of technology diffusion etc.).

The second of these suggested approaches can be expanded upon given the codifiable nature of the alternative SNA metrics. Functionality comparatives were made *within* the system and between the following different sub-divisions to draw out comparative high and low performers:

- Different actors
- Different countries, (specifically England and Scotland),
- Different sub groups,
- Different knowledge networks
- Different patents
- Different systems (specifically a brief comparison between the wave and tidal sectors within the UK)
- Different technology developers themselves.

Through discussion and assessment of these comparisons as well as the overall collective findings of the interview and primary research phase, key inducement and blocking mechanisms were identified, (be they actors, institutions , established networks etc.). These were then be explored and elaborated on in a narrative format within the later part of this section.

5.8.2 Policy Recommendations (Specifying Policy Issues)

The final section of the discussion section identifies and elaborates key policy recommendations that could help to mitigate negative elements identified as present within the system based on the cumulative findings and earlier part of the chapter discussion (such as technology lock-in or functionality failure as outlined within the Inhibitors of Innovation and Innovation Systems sections of Chapter 2, the Literature Review (2.3.5 and 2.3.3). As Bergek states, this section attempts to try and look at way of "strengthening/adding inducement mechanisms and weakening/removing blocking mechanisms" (Bergek *et al.*, 2008a).

5.9 Conclusive Remarks

In summary of the preceding methodology; the process of data gathering itself was split into two stages: A desktop based study and a primary interview stage. Both of these were, (by necessity) undertaken concurrently were relevant and necessary to both the existing and extended SNA metric data gathering process. The interview stage was conducted using a snowballing referral methodology until saturation of the network under inspection (the UK wave energy sector) was achieved. While finding who people had been interacting with, (a stated proxy for knowledge exchange) interviewees were asked a wide range of other questions, both quantitative and qualitative. All of these metrics, combined with the desktop study, were synthesised within the later stages of the assessment to explore the individual *functionalities* of the system. This in turn then allowed for final analysis of the *health* of the system overall. From and through the process of assessment, the primary research questions within the study were answered.

The following two chapter therefore presents the primary findings of the study with the immediate next, (the Established Findings Chapter 6) clearly being those that are highlighted within existing literature as being relevant to examine. This shall then be followed by the additional SNA metrics findings before; (within the later section of this thesis) the various discussion sections are explored.

6. Established Findings and Calculations:

Table of Figures:

Table of Tables:

6.1 Chapter Introduction

This chapter outlines the bulk of the calculations and findings from the primary data gathering process, the aim being an analysis of the wave energy sector using 'status-quo' indicators as outlined by predecessors works on technological innovation systems analysis (TIS) (Bergek *et al.*, 2005, Bergek *et al.*, 2008a, Bergek and Norrman, 2008, Bergek *et al.*, 2008b, Carlsson and Stankiewicz, 1991, Carlsson *et al.*, 2002, Chang and Chen, 2003, Hekkert *et al.*, 2007, Hekkert and Negro, 2009, Jacobsson and Johnson, 2000, Johnson and Jacobsson, 2003, Liu and White, 2001, Negro, 2007, Winskel *et al.*, 2006, Shum and Watanabe, 2009).

The order in which the functionalities occur has no bearing upon the importance of their affect on the system of analysis, although Bergek suggests that 'legitimation' and 'development of positive externalities' are the most crucial factors influencing the formation of early stage TIS's such as the wave energy sector (Bergek *et al.*, 2008b).

Findings are presented and analysed here where appropriate. Interpretation of results as well as the 'validity' of different metrics (both in terms of their empirical value and in terms of their synthesised meaning to the emerging sector) is left to the last two chapters in which the combined system functionalities are discussed.

6.2 Resource Mobilization

6.2.1 R&D Spend

The UK wave energy funding landscape is a complicated mix of shifting funding opportunities and conditionality that is almost continuously being revised, added to, and in some cases scrapped. Gathering clear data on UK marine energy funding and specifically wave energy funding is not straightforward. There is little refined definition as to what is public wave energy sector funding, (e.g. whether spending on infrastructural support or test centres should be included with conventional academic and industrial support funding programmes), and whether funding spent or committed (and indeed how much of committed funding has been spent) should be included within the data.

IEA spend data for the UK (presented in Figure 27 (IEA, 2010)**Error! Reference source not found.**) show that there has been an increase in the UK's ocean energy R&D spend over the last decade (amounting to the equivalent of £24M1 up to 2008) following on from a landscape of almost absent funding throughout the 1990s.

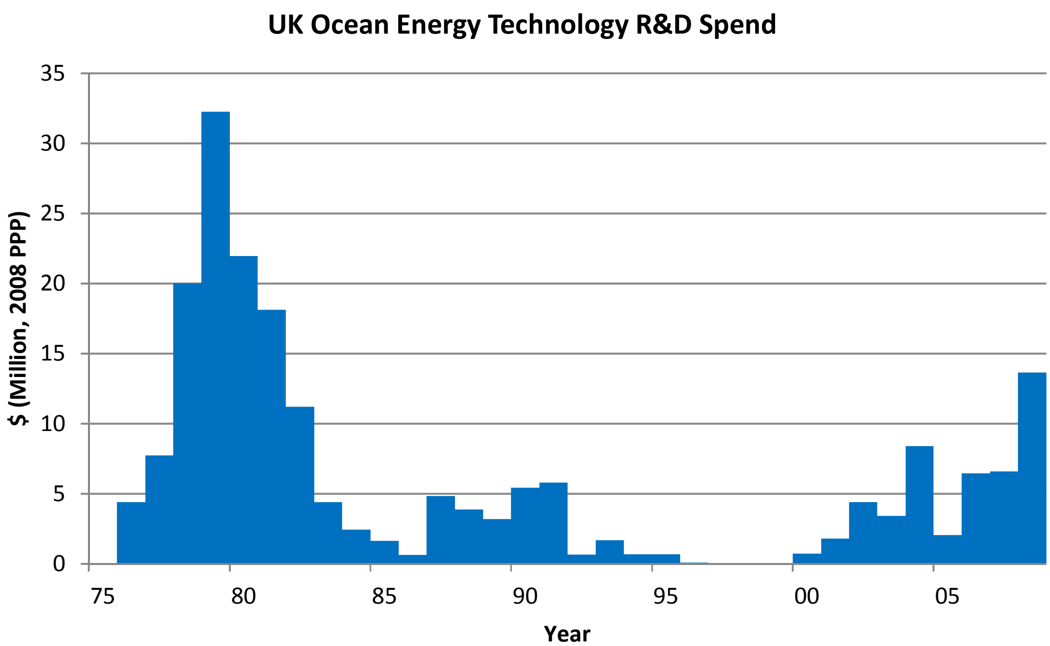


Figure 27: IEA, UK Ocean Energy Technology R&D Spend

These figures however hide many of the joint private/public spending statistics as well as cross-cutting technology research and have been criticised for being non-reflective of the current structure and content of today's R&D expenditure (European Commission, 2005).

The findings of the primary data gathering stage have identified a far higher level of support (although this finding is for committed spending as well as 'already spent' sums) than that shown in the IEA data. A summation of the current and prior funding spent over the last decade is presented in Table 10 and Figure 28 below[2]:

---

[1] Calculated based on sum total of $47.515M 20008 PPP and an exchange rate (for June 2008) of 1.943 $/£ HM Revenue and Customs *Rates of Exchange for Customs and VAT purposes 06-2008,* HM Revenue and Customs, http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageVAT_RatesCodesTools&propertyType=document&id=HMCE_PROD1_028625, 2011, 23rd of March.

[2] Note that the MRDF is not included within this support since it failed to receive access during its operational period. This failure is discussed further within the System Discussion Section 10.2.2a.

Funding Agency/Manager:	Project:	Funding (M£)	Reference:
BERR, (Now BIS)	BERR Tech. Prog	26	(Renewables Advisory Board, 2008)
The Carbon Trust	CT's App. Res. Prog	3	(Renewables Advisory Board, 2008)
The Carbon Trust	CT's MEA	3.5	(Renewables Advisory Board, 2008)
The Carbon Trust	CT's Marine Energy Challenge (MEC)	3	(Mueller, 2009)
The Carbon Trust	CT's MRPF	22	(Carbon Trust, 2009b)
EMEC	EMEC	22.5	(Renewables Advisory Board, 2008, DECC, 2009)
EPSRC	EPSRC Responsive Grants	15.14	Personal Communications with EPSRC (R.Cox on 14/12/10)
ETI	ETI's PerAWaT	8	(Richardson, 2009)
NaREC	NaREC (Marine)	20	(Renewables Advisory Board, 2008, DECC, 2009)
The Scottish Government	Scot. Gov's WATES	7.37	Personal Communication with Scottish Government (J. Steel on 22/12/10)
EPSRC	Supergen 1 & 2	8.05	(Renewables Advisory Board, 2008, Mueller, 2009) Personal Communications with EPSRC (R.Cox on 14/12/10)
SWRDA	SWRDA	10.3	(SWRDA, 2009)
The Scottish Government	The Saltire Prize	10	(POST, 2009)
TSB	TSB Competition	9.5	(Technology Strategy Board, 2010, Technology Strategy Board, 2011)
NERC	UKERC's Marine Network	0.17	(Mueller, 2009)
SWRDA	Wave Hub	42	(Clark, 2010)
The Welsh Assembly Government	Welsh Ass. Objective 1 Funds	6	(Renewables Advisory Board, 2008)
The Scottish Government	Scot. Gov's WATERS	13	(Scottish Government, 2010a)
Crown Estates	Enabling Actions Fund	5.6	(Crown Estate, 2010c)
Total:		235.13	

Table 10: Summative Findings of the UK Marine Energy Spend up until 07/11 (and Commitment) Over the Past Decade, (Inclusive of Test Centres)

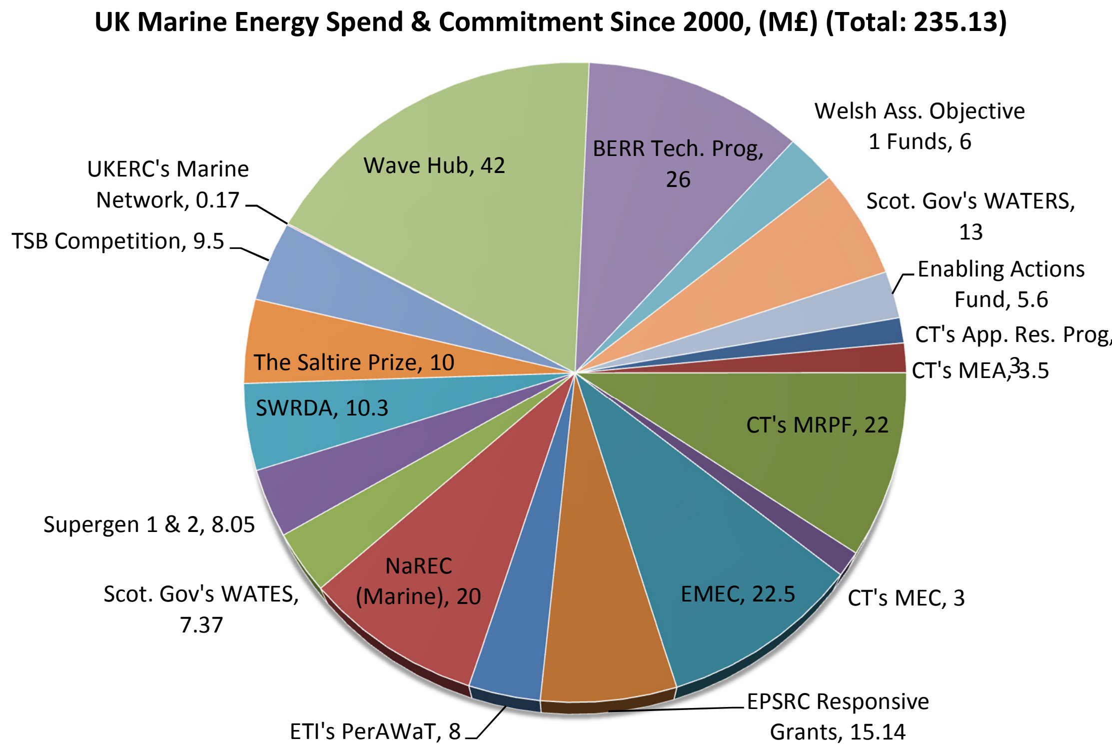


Figure 28: Summative Findings of the UK Marine Energy Spend between 2000 and 07/11 (and Commitment), Inclusive of Test Centres

The overview of how much money has been spent or committed does not fully explore the important aspects of how the funding has been distributed, to whom it is distributed, the conditionality that exists around accessing the funding and what the outcome efficacy of that support was. The above findings also exclude European research which accounts for around €37m of projects (many of which are joint wave/tidal or joint offshore) identified in Table 11 below:

Programme	Invested	Status
SOWFIA	€1.9m	Active
SEANERGY 2020	€1.24m	Active
MERiFIC	€2.5m	Active
OFFSHOREGRID	€1.39m	Closed
MARINA PLATFORM	€8.71m	Active
WAVEPORT	€4.59m	Active
EQUIMAR	3.99m	Complete
CORES	3.45m	Complete
PULSE STREAM 1200	€8.01m	Active
ORECCA	€1.6m	Complete
Total	€37.38m	

Table 11: Summative Findings of EU Marine/Offshore Renewable Energy Spend Between 2000 and 07/11 (Including Mixed Offshore RE Technology)

The main funding schemes currently available to device developers can be sub-divided into grant supports (technology push mechanisms) and revenue support (market pull mechanisms). The transition towards the latter is starting to occur for some of the most mature technologies, however a high level of grant subsidy is still being provided to overcome the initial risks of technology deployment, faced before 'learning by using' can ensue. The main sources of public sector funding and their compatibility are shown in Table 12 below:

	Carbon Trust/TSB/other QUANGO	MRPF (Closed)	MRDF (Un-Accessed and Closed)	WATERS	WATES (Closed)	2 ROCs (England)	5 ROCs (Scotland)
Carbon Trust/TSB/other	-						
MRPF (Closed)		-		x	x		09/08>
MRDF (Un-Accessed and Closed)			-	x	x		09/08>
WATERS		x	x	-		x	09/08>
WATES (Closed)		x	x		-	X	09/08>
2 ROCs (England)				x	x	-	x
5 ROCs (Scotland)		09/08>	09/08>	09/08>	09/08>	x	-

Table 12: Main Sources of UK Device Developer Funding Compatibility (Green is Compatible While Red is Not)

Additionally, the various funding conditionality's of funding are outlined in Table 13 below:

	Programme Sum (M£)	Individual Project Maximum (M£)	Conditionality	Capital Weighting (%)	Capital Ratio (To Project)	Revenue Weighting (%)	Revenue Level (£ per MWh)	Time Period	Programme Start Period	Programme End Period
2 ROCs	-	n/a	per/MWh	0	-	100	97.60*	-	09/10	03/37
5 ROCs	-	n/a	per/MWh	0	-	100	244.00*	-	09/10	03/37
CCL Exemption Cert.	-	n/a	per/MWh	0	-	100	4.70**	-		
CT's App. Res. Prog	3	<0.25	Appraisal	100	40<65%	0	-	<3yrs	06/05	-
CT's MEA	3.5	1.2 (EMEC)	Appraisal	100	<£1.2M	0	-	2yr	10/06	03/10
CT's MEC	3	n/a	n/a	100	n/a	0	-	18m	01/04	06/05
CT's MRPF	22	6	Appraisal	100	60%	0	-	15m	09/09	03/11
MRDF	42	9	Appraisal	-	25%	-	100.00	7yr	02/06	-
Scot. Gov's WATERS	15	6	Appraisal	100	<£6M	0	-	n/a	07/10	07/10
Scot. Gov's WATES	13.15	5	Appraisal	-	40%	-	100.00	5yr	2006	03/08
The Saltire Prize	10	10	100GWh+ 2 year (1st)	100	£10M	0	-	2yr (Ass)	12/08	07/17
Welsh Ass. Objective 1 Funds	6	no detail	no detail	no detail	no detail	no detail	no detail	no detail	no detail	no detail

Table 13: Main Sources of UK Device Developer Funding Conditionality[3]

From a device developer's perspective, this funding can be translated as providing discrete support for technologies at different stages of technological maturity being funded by different public sector, (or QUANGO) bodies (see Chapter 3, Background Review of the Sector (3.4.3) for further details) . This funding pathway roughly travels from research councils at the initial concept stages (as well as some CT funding), through to technology strategy board and energy technology institute funding at a scale model testing stage, through to central government measures such as the MRPF and MRDF at the large/full scale prototype testing and beyond as can be seen in Table 14 Below:

---

3 * figure based on average ROC price of £48.80 as of 24/03/11
** CCL Based on average price of £4.70 as of 24/03/11

	TRL	Step Location:	Public Funding	Private Funding
R&D:	1	Office	Not Available	Friends & Family
	2	Office	EPSRC	Friends & Family
	3	Office/Laboratory	EPSRC / CT	Friends & Family
	4	Laboratory/Testing Tank	EPSRC / TSB / CT	Angel Investors
	5	Tank Testing/ Scale Test Facilities e.g. NaREC	TSB(ETI)	Angel Investors
	6	Scale Test Facilities e.g. NaREC	TSB / RDAs	Angel Invest / Venture Cap
Demonstration:		**System Validation**		
	7	Full Scale Test Facilities - EMEC	CT / RDAs / Dev. Admin	Venture Capitalists
	8	Full Scale Test Facilities - EMEC	CT / RDAs / Dev. Admin	Venture Capitalists
	9	Full Scale Test Facilities - EMEC	CT / RDAs / Dev. Admin	Utility / Venture Cap
Pre-Commercial:		**Commercial Validation**		
	10	Pre-Commercial Deployment EMEC/Wave Hub	DECC / Dev. Admin	Utility
	11	Pre-Commercial Deployment Wave Hub/Pentland Firth	DECC / Dev. Admin	Utility / Bank

Table 14: Sources of Public and Private Funding for Device Developers at Different Stages of Development

One of the strong qualitative findings from the primary interview stage was that funding policies - although generally perceived to be too low for our targeted ambitions - were far too piece-meal, sporadic and effectively lacking in 'technology development flow'. Some device developers believed that public spending was effectively being 'wasted' on sub-component or partial device validation experiments that left only half complete devices without funding or revenue source. In effect, there was a lack of flow in progressing device developers through funding bodies such as from Carbon Trust support to ESI/TSB or DECC support. As a result of this patchy chronological support, many developers have been forced to exit the industry and those that have stayed have generally had to keep operating overheads to an extreme minimum until they could secure commercial alliances with larger investors such as utility companies or other large multinational corporations.

> "Funding tranches are too project specific; narrow in their resolution when compared to the larger project overall and 'fashionable' (i.e. based on the zeitgeist of the sector)."
>
> Device Developer

Where continuous support was provided, 50/50 leverage funding (required as a result of European competition laws) prevented uptake from all but the most market ready technologies. Less mature developers have found it hard even to access this match-funding since the equity value of their companies is itself not high enough to attract investors.

There is more to fiscal mobilisation than the amount of research that is funded in a sector. The method by which it is accessed and spent dictates much of the direction of support. This is discussed further within the Methodological Discussion section, 9.3.1a.

"Within the landscape, there are a number of technologies that have got potential but in terms of how public money is spent, it might not be appropriate at different stages for us to be stepping in to do it. You might have a technology that has potential however the way in which the company assesses the key risks about that technology (such as accessing funding to private capital and angel funding) are really key. There's a balance between technological and non-technological factors."

DECC

6.2.2 Skills and Employment Mobilisation

6.2.2a Employment

The second form of resource mobilisation (along with finance support) is that of skills and labour. The following section outlines the relevant findings from the primary research.

There Is relatively little literature on skills and employment expectations for the marine renewable sector, and poorly articulated methodologies for both deriving and displaying these figures are a common problem (Dalton and Lewis, 2011). The primary reason for this is that employment estimates are calculated based upon deployment expectations, which (as can be seen in the Influence Upon the Direction of Search section 6.3.1 of this chapter) are still currently at an unrefined state.

None-the-less, some estimates have been made on broad employment expectations of the sector in absolute numbers as can be seen in Table 15 below:

Author	Employment expectation in sector by year				
	2015	2020	2035	2040	2050
DECC (Wave)	na	na	na	16000	na
Carbon Trust (Wave)	na	na	na	16000	na
RenewableUK (Marine)	na	10000	19500	na	19000
Offshore Valuation Group (Low) (Wave)	na	na	na	na	2000
Offshore Valuation Group (Med) (Wave)	na	na	na	na	4000
Offshore Valuation Group (High) (Wave)	na	na	na	na	4000
Scottish MEG (Low) (Marine) (Scotland)	na	2850 (1500 in Scot)	na	na	na
Scottish MEG (Med) (Marine) (Scotland)	na	5000 (2600 in Scot)	na	na	na
Scottish MEG (High) (Marine) (Scotland)	na	10000 (5300 in Scot)	na	na	na
WaveNet (Wave) (Scotland)	1600	na	na	na	na
EU-OEA (Europe) (Marine)	na	26000 (Dir) 314213 (Ind)	na	na	314213 (Dir) 471320 (Ind)

Table 15: Wave and Tidal Sector Employment Estimations (Wavenet, 2003, Carbon Trust, 2009a, DECC, 2010b, RenewableUK, 2010a, The Offshore Valuation Group, 2010, Scottish Government, 2010b, European Ocean Energy Association, 2010)

One common framework used for analyses of employment levels is to assess the different ranges of skills required as well as involvement within the sector, and then categorise them into, direct jobs and indirect jobs. ‘Direct jobs’ refers to specialised skills and labour that are specific to the sector and will potentially be in shortage, for example specialist divers, direct manufacturers, offshore installation engineering specialists, employees capable of major R&D programmes and workers within utility companies involved with the power purchase and sale of the energy generation. Indirect jobs include auxiliary skills such as legal and accounting services, sporadic employment and intermediate goods or services that are required to realise deployment targets. These auxiliary skills will come from a larger pooled market and will not require specific training (or rather, training policy initiatives) for the marine energy sector to develop (EWEA, 2008).

One of the few direct analyses of the wave energy sector (and using the direct/indirect employment framework) was carried out by Southampton University and suggests 6.5 direct and 3 indirect employees for every €1m of installed capacity (totalling 9.5 jobs/€1m) as shown in Figure 29 below (Bahaj and Batten, 2005).

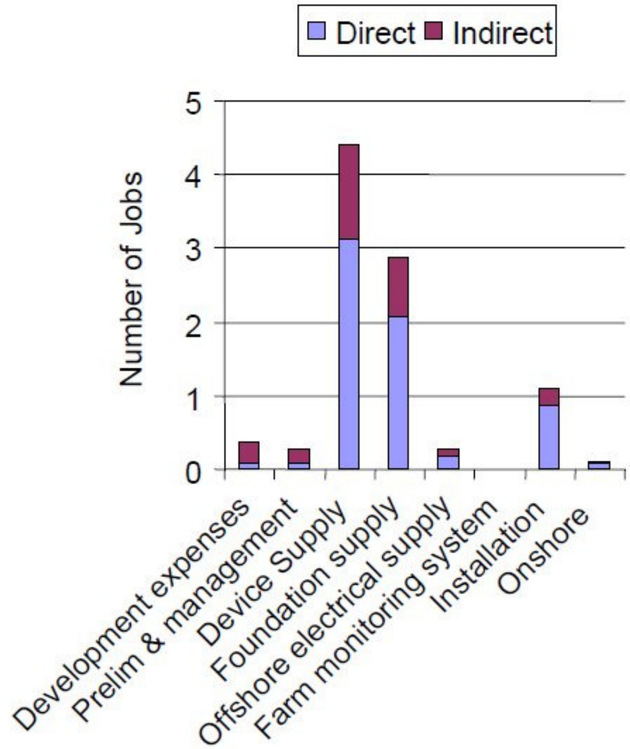


Figure 29: Direct and Indirect Employment Estimations per MW of capacity installed for Wave Energy (Bahaj and Batten, 2005)

This figure is equivalent to 7 (combined direct and indirect jobs) after learning effects by 2020, and was calculated using the Carbon Trust's 2020 European deployment estimate of 1,000MW-2,500MW at an overall capital cost of £1,000m/£2,500m (Carbon Trust, 2006). When converted therefore at roughly £1m - £1MW for post learning production line deployment, this figure is not too dissimilar from that obtained by RenewableUK and the Scottish Government, who estimate 6.7 and 5→5.7 direct jobs/ MW respectively by 2020 (RenewableUK, 2010a, Scottish Government, 2010b). Dalton also cites PB&A employment estimates for marine energy of 9 jobs/MW, (direct and indirect) by 2020 in Ireland (Peter Bacon & Associates, 2005, Dalton and Lewis, 2011). The only actual analysis done so far and based on real case scenarios was on the Wave Dragon Project in 2001, which found slightly higher figures of 10 direct jobs and 5.3 indirect jobs required, however this was for a prototype project and thus has been assumed somewhat high (given the expectation of learning effects to increase efficiency of build) (Peter Bacon & Associates, 2005).

This early stage ratio of between 5→6.7 direct and around 3 indirect jobs /MW are all made under the assumptions of an increasing construction based ratio (i.e. almost all the jobs are in manufacturing and deployment) with employment matrix multipliers used to assess indirect job numbers.

As time and deployment increase however, estimations become far harder to make as factors affecting both the actual employment statistic as well as clarification of reporting measures become more prominent. The number of direct and indirect jobs alters as capacity building efficiencies increase, (i.e. changing from bespoke units supply to a larger supply chain). Additionally, as the availability of the most economically favourable sites' availability decreases, (or developers move further offshore) the level of work needed to deploy the same capacity might be expected to increase (The Offshore Valuation Group, 2010).

With regards to the reporting measures, as the total level of capacity increases, the number directly employed within O&M will increase, distorting the jobs/MW figure (With a rough estimate of 0.32 O&M jobs/MW). Likewise, the effects of both an import and export market for the capital equipment will skew any jobs/MW ratio.

These distortions mean learning efficiency factors to employment ratios are hard to calculate, since employment projections to 2050 and other long term targets include both maintenance figures as well as the export/import factors. Estimates suggest that the roughly expected jobs/MW reduces to around 3.5<4.6 direct jobs/MW by this time (Bahaj and Batten, 2005, Peter Bacon & Associates, 2005).

One of the more significant problems with calculating the number of jobs created for marine renewable energy is that figures are often given in jobs/MW scale (as above) which does not provide adequate information as it reveals nothing of the time dimension of these jobs, (i.e. whether they averaged out (mean) jobs per year over the project life, peak jobs etc.). A more accurate metric would be to provide either fully jobs-years equivalence for the project or jobs/MW/year (Dalton and Lewis, 2011, Peter Bacon & Associates, 2005).

6.2.2b System Interview Numbers

All Interviewees were asked in question 6(a) to provide the number of direct FTE employees that they held currently working within the wave energy sector working in the categories of; 'technical', 'market', 'environmental and planning' and 'other' (representing supporting staff and administration working directly on wave energy). This 'bottom up' approach to the establishment of employment statistics proved challenging to answer for some respondents, since many staff work part time or only partly on wave energy, within different and often segregated departments (especially so within universities), or were not sure which particular discipline they would be considered to reside in, (i.e. fiscal/market or technical etc.) Table 16 and Table 17 below show the resultant findings for all 468 employees mentioned.

Total Respondent FTE Employees (By Actor Type)				
Actor Type\Discipline	Tech	Market	Enviro/ Planning	Other
Device Developer	171.50	33.00	19.50	8.00
Utility Company	18.33	7.58	6.58	2.00
Government Department	1.33	8.93	5.83	0.00
University or Research Centre	101.02	11.55	32.55	3.00
Test Centre	19.00	5.00	5.50	8.00
Total	311.18	66.06	69.96	21.00

Table 16: Summated Interviewee Response to Number of FTE Employees

Mean FTE Employees (By Actor Type)				
Actor Type\Discipline	Tech	Market	Enviro/ Planning	Other
Device Developer	12.25	2.36	1.39	0.57
Utility Company	3.67	1.52	1.32	0.40
Government Department	0.33	2.23	1.46	0.00
University or Research Centre	7.22	0.83	2.33	0.21
Test Centre	6.33	1.67	1.83	2.67
Mean Total	7.59	1.61	1.71	0.51

Table 17: Mean Interviewee Response to Number of FTE Employees

Although these finding do not represent the entirety of the wave energy sector, (since there was not a 100% response rate), the mean FTE figures can be transposed to assess the overall levels of employment for non-respondents actors.

If this is done (excluding respondents who claimed not to be active within the sector) the resulting additional employees are calculated as shown in Table 18 below:

	Total (Calc) Additional FTE Employees			
	Tech	Market	Enviro/ Planning	Other
Device Developer	36.75	7.07	4.18	1.71
Utility Company	3.67	1.52	1.32	0.40
Government Department	1.66	11.16	7.29	0.00
University or Research Centre	72.16	8.25	23.25	2.14
Test Centre	0.00	0.00	0.00	0.00

Table 18: Summated calculated Additional Number of FTE Employees for Non-Respondents

When summed with the actual interview findings this gives the final direct wave energy sector employee figures of 650 broken down as shown in Table 19 and Figure 30 below:

Total Wave Energy Sector Calculated FTE Employees (By Actor Type)				
Actor Type\Discipline	Tech	Market	Enviro/ Planning	Other
Device Developer	208.3	40.1	23.7	9.7
Utility Company	22.0	9.1	7.9	2.4
Government Department	3.0	20.1	13.1	0.0
University or Research Centre	173.2	19.8	55.8	5.1
Test Centre	19.0	5.0	5.5	8.0
Total	425.4	94.1	106.0	25.3

Table 19: Calculated Total Number of FTE Employees within the UK Wave Energy Sector

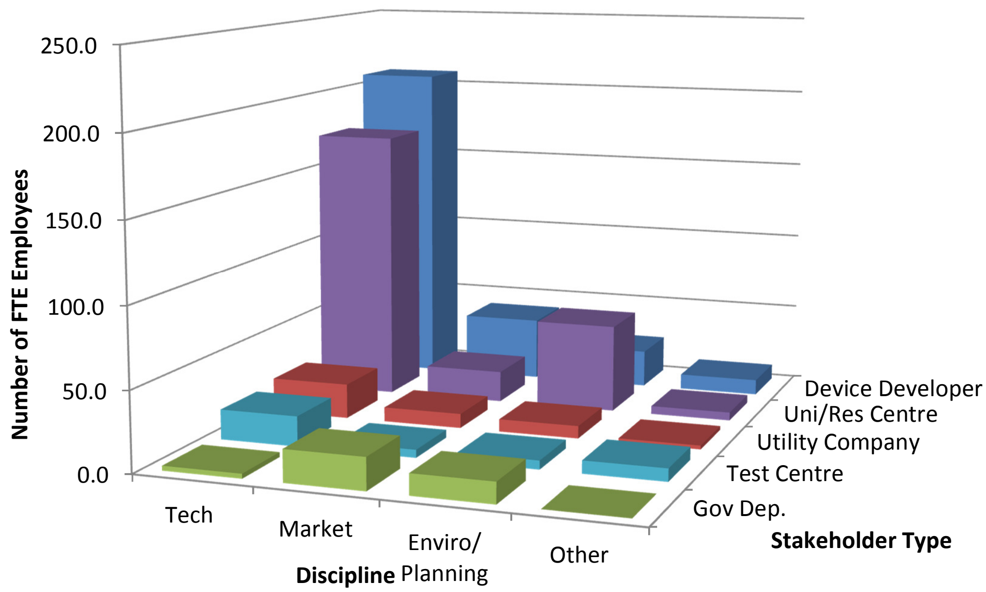


Figure 30: Calculated Total Number of FTE Employees within the UK Wave Energy Sector

6.2.2c Skills and Education

There have been several detailed skills requirement studies published on combined offshore wind, wave and tidal technologies (Energy for Sustainable Development Ltd, 2004, Adams Associates UK Ltd, 2007, SQW Energy, 2008) although very few have focussed specifically on wave energy technology. This is because, although these are clearly different sectors, there are many identified overlaps within both manufacturing and project development (such as cable laying, sub-station construction and marine engineering) that can be seen as complementary and transferable between the three sectors (Wavenet, 2003, Pricewaterhouse Coopers LLP, 2010).

Although it is hard to categorise skills as 'marine energy specific', there is a general consensus as to the type of skill bases that are required for the marine energy sector to emerge. As with employment levels, many of the skills required for working in marine renewables (or specifically within wave energy commercialisation) are considered to be at some level transferable, and thus a dual focus on both transferability (through 'up-skilling') of the existing workforce, and focussing on high level (NVQ 5<8) specialised training for specific skills gaps. These have been broadly identified as the most effective approach to addressing the sectors skill requirements (emd, 2010, SQW Energy, 2008, Adams Associates UK Ltd, 2007, Future Energy Solutions, 2002). These two categories can be broken down further then into the more specifically identified problems below:

6.2.2d Skills Transferral and Up-Skilling

Transference of existing skilled labour markets includes the crossover (or 'free-utility' of labour) from related industries such as oil, gas, and wind/offshore wind as well as more generalised skilled labour such as electrical, mechanical and maritime industries. Many of the work-force from these industries can be 'up-skilled' to complement the emerging marine energy sector through specific training in courses such as sea survival, rope access, marine engineering and first aid training.

A list of indicative vocational skills trainings is listed in Table 20 below:

Certification:	Certification Body:	Description:	Duration:
Basic Offshore Safety Induction & Emergency Training	Offshore Petroleum Industry Training Organization (OPITO)	Basic requirement for personnel intending to work on an offshore installation in the UK	3 Day
Personal Survival Techniques Certification	Standards of Training, Certification and Watchkeeping (STCW)	Basic requirement certification that is required for all contractors intending to work offshore. (Including boat works)	1 Day
Offshore Medical Certificate UK	United Kingdom Offshore Operators Association approved physician	Basic medical certification required for all offshore works (Including boat works)	NA
WTG Wind Turbine Climber Certification	British Wind Energy Agency	Basic course for working within wind turbines, (potentially transferable to wave/tidal devices)	2 Day
Rope Access training Certification (1<3)	Industrial Rope Access Trade Association	Differing levels of rope access certification required for all rope access works	5 Days +
Slinging and lifting Certification	Various	Certification Required for "Lifting Operations and Lifting Equipment Regulations 1998" (LOLER)	1 Day

Table 20: Indicative vocational skills training options for transferral of skilled labour to work within marine renewable energy

In addition to these skills, it is recognised that there will be a need for experience to be gained, (learning by doing) through deployment that will provide higher tacit understanding of the nature of the work for those employed in deployment and O&M. Acknowledging this, there will need to be carefully managed transition from the project R&D to large scale deployment that will require clear stages of certifications (see Legitimacy of devices in this chapter, Section 6.6.5) and a managed incremental deployment to allow this learning to ensue.

6.2.2e Specific High Level Training

Although they would constitute only around 10-20% of the direct workforce, most documents related to offshore renewable energy skill requirements (and specifically for marine or 'wet' technologies) have identified a pressing need for high level (NVQ 5<8) science, technology, engineering and mathematics (STEM) qualified labour specifically for the purpose of (device and project) design/control and project management engineering (emd, 2010, Scottish Government, 2010b, SQW Energy, 2008, Adams Associates UK Ltd, 2007, Energy for Sustainable Development Ltd, 2004, Social Research & Regeneration Unit, 2003, Future Energy Solutions, 2002, RenewableUK, 2010a, Bahaj and Batten, 2005).

> "More engineers and skilled technicians are required at this stage in industry. Supply chains will be critical later but not now."
>
> Device Developer

Various lists of skill sets have been compiled- such as that shown in Figure 31 (from SQL's offshore skills set document) and the more detailed; Occupational and Functional Map Renewable Energy Sector (Adams Associates UK Ltd, 2007). It has been concluded that a wide range of technical competencies will be required initially focussed within RD&D activity and, once a predominant design becomes apparent and there is a 'shake-down' of technology heterogeneity within the sector, these high-level skills will move towards more established offshore engineering competencies, (such as are required for oil and gas as well as current offshore wind development), marine environmental consultancy and general power and mechanical engineering skills.

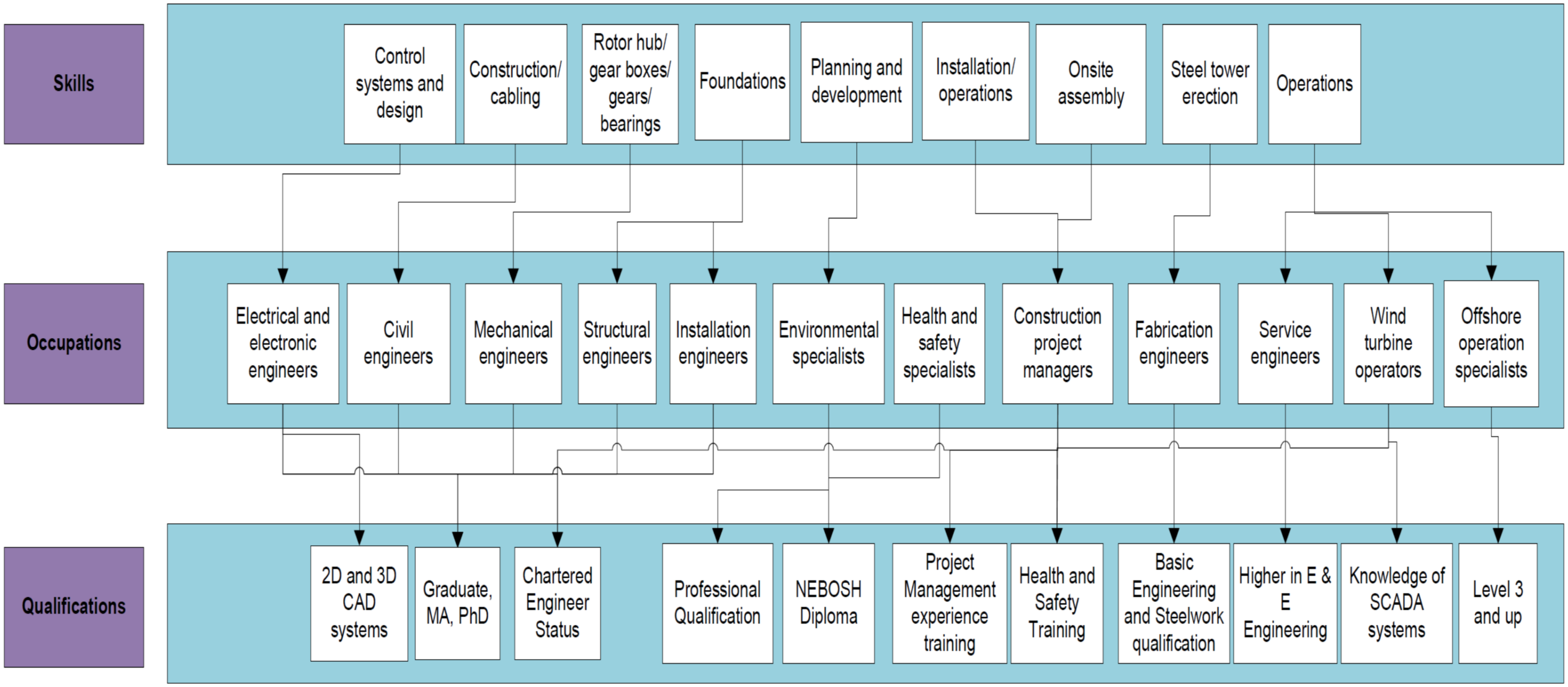


Figure 31: Skills, Occupations and Qualifications within the WWT sector (SQW Energy, 2008)

6.2.2f Research Staff Numbers

As with employment number statistics, university-based interviewees were asked (in question 6(b)) to provide postgraduate numbers for PhD students working within technical, market/fiscal and environmental and planning disciplines of the wave energy sector. Responses are shown in Table 21 below:

	Total Respondent FTE PhD Students		
	Tech	Market	Enviro/ Planning
Total	64	4	20
Mean	4.57	0.29	1.43

Table 21: Summated Interviewee Response to Number of FTE PhD students

This number is heavily skewed by the University of Edinburgh which has just under half of the total number of technical PhD students. Taking this obvious outlier out of the sample for a more reflective assessment of Phd student numbers, the mean average number of specialist students studying at wave energy active universities within the UK is 3, 0.31 and 1.54 for Technical, Market and Enviro/Planning PhD students respectively.

Given the 8 universities within the sector who did not respond to the interview request, the number of PhD students at these institutions can be interpolated based on the mean student values (excluding Edinburgh as an outlier) to give an estimation of the total number of FTE PhD students working within the UK wave energy sector as shown in Table 22 below.

Calculated Total UK Wave Energy PhD Students			
	Tech	Market	Enviro/ Planning
Respondents	64	4	20
Non Respondents	24	2.46	12.31
Total	88.00	6.46	32.31

Table 22: Calculated Total Number of FTE PhD students within the UK Wave Energy Sector

This summated figure of 127 students can be assessed in context of other indicators including UKERC's 2009 Marine Renewable Energy Research Landscape document, in which the last publication of PhD student figures was 145 (Mueller, 2009).This figure however is not directly comparable since the UKERC figure includes tidal technology students (and was published in 2009, later publications excluded PhD student numbers).

A similar analytical process can also be done with all Masters' students. Results showed a total of 98 students (working with dissertations or a specific Master's course on wave energy). The discipline breakdown is shown in Table 23 below:

Calculated Total UK Wave Energy Post Grads			
Respondents	59	6	9
Non Respondents	14.77	3.69	5.54
Total	73.77	9.69	14.54

Table 23: Summated Interviewee Response to Number of FTE Masters Students

6.3 Influence upon the Direction of Search

Exclusive deployment expectations for wave energy have not been made by DECC, however looking at current support for demo and licensing agreements, there is an expectation that there is a roughly equal capacity building ‘push’ for both wave and tidal energy at this stage of industrial development (Crown Estate, 2010a). This is despite the recently revised larger resource potential and cheaper current generation cost for tidal energy (The Offshore Valuation Group, 2010, Committee on Climate Change, 2011). Although tidal energy is recognised as a cheaper technology at present, when capacity reaches higher levels, it is predicted that wave energy will start to take the lead on deployment when optimum tidal sites are used up, (see resource assessment under Chapter 3).

6.3.1 Government Influence upon the Direction of Search

Government 2020 deployment goals for marine renewables have recently been reduced to a centralised estimate of 300MW within DECC’s Renewable Energy Roadmap (DECC, 2011b). This is down from a previously ambitious 1-2GW capacity announced within the 2010 Marine Energy Action Plan (DECC, 2010b). Both documents expect a significant increase towards 2030 and beyond. This revised capacity of 300MW is expected to arise through an aggregation of smaller site developments (such as the Pentland Firth development) as outlined in Figure 32 below:

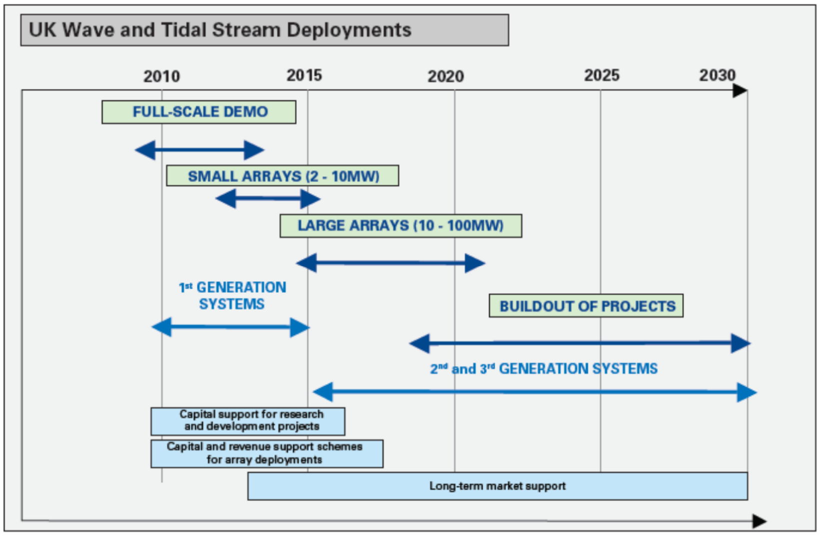


Figure 32: DECC's proposed marine renewable deployment plan until 2030.(DECC, 2010b)

Several other prominent stakeholders have also made projections on their expectations of deployment capacity for marine renewables for 2020. Specifically, deployment roadmaps have been made by the CT, the ETI (with UKERC), RenewableUK, the Offshore Valuation Group (an industry led adlib body), and the Forum for Renewable Energy in Scotland's Marine Energy Group, (MEG). Deployment expectations for the UK as well as the technology 'resolution', (i.e. for wave or marine overall) are shown in Table 24 and Figure 33 below. It should be noted that the mean average values of ranges have been plotted in Figure 33.[4]

[4] Dates with na filled in have not been provided and are thus not applicable.

Author\Year	Capacity, (GW)					
	2013	2020	2025	2030	2040	2050
DECC (Marine)	na	0.30	na	2.60	na	27.00
Carbon Trust (Marine)	na	2.00	na	na	na	na
UKERC/ETI (Marine)	na	1.50	na	9.00	13.50	15.00
RenewableUK (Marine)	na	1.50	na	na	na	36.00
Douglas-Westwood (Marine)	0.051	na	na	na	na	na
Bain & Company (Marine)	na	1.40	na	na	na	na
Offshore Valuation Group (Low) (Wave)	na	1.00	na	2.00	2.00	2.00
Offshore Valuation Group (Med) (Wave)	na	1.00	na	5.00	5.00	5.00
Offshore Valuation Group (High) (Wave)	na	1.00	na	4.00	11.00	14.00
Sinclair Knight Merz (Low)(Wave)	na	0.03	na	na	na	0.84
Sinclair Knight Merz (Med)(Wave)	na	0.23	na	na	na	1.69
Sinclair Knight Merz (High)(Wave)	na	0.58	na	na	na	2.65
Scottish MEG (Low) (Marine) (Scotland)	0.075	0.50	na	na	na	na
Scottish MEG (Med) (Marine) (Scotland)	0.150	1.00	na	na	na	na
Scottish MEG (High) (Marine) (Scotland)	na	2.00	na	na	na	na
Welsh Ass. Gov (Marine) (Wales)	na	na	4.00	na	na	na

Table 24: Future UK Deployment Models for Both Wave and Marine Renewables (DECC, 2010b, Carbon Trust, 2009a, Energy Technologies Institute, 2010, RenewableUK, 2010a, Douglas-Westwood, 2008, Boettcher *et al.*, 2008, The Offshore Valuation Group, 2010, Sinclair Knight Merz, 2008, Scottish Government, 2010b, Welsh Assembly Government, 2010, DECC, 2011b).

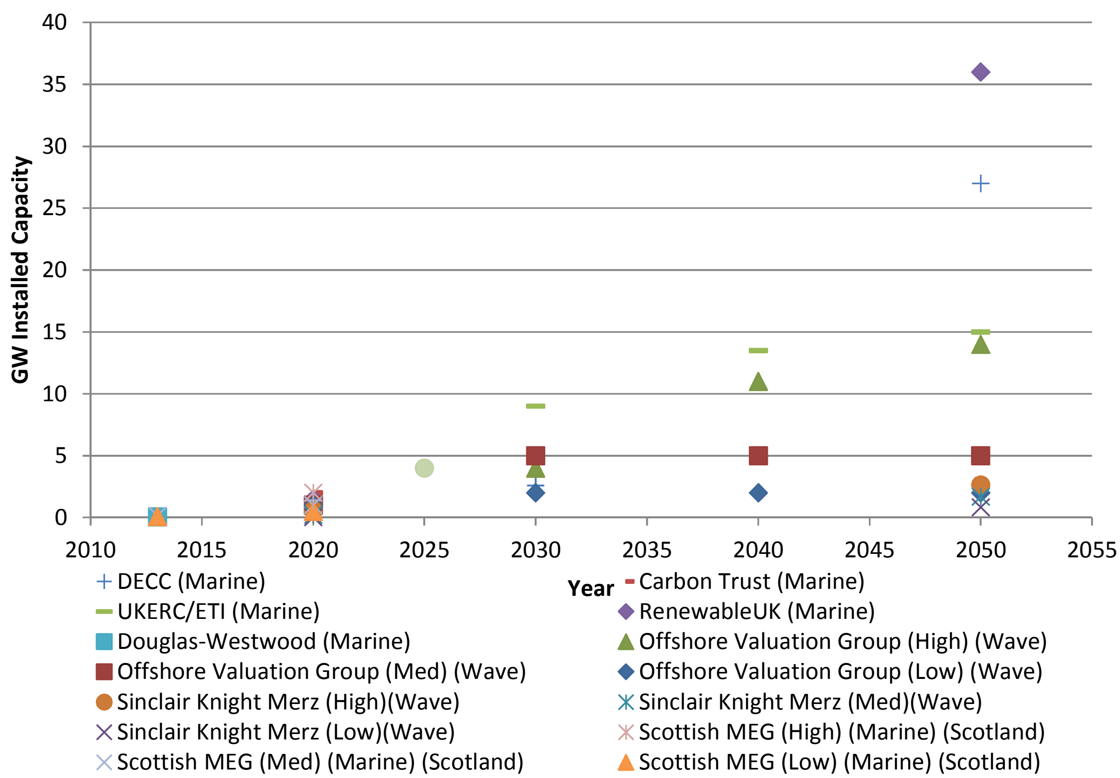


Figure 33: Future UK Deployment Models for both Wave and Marine Renewables (DECC, 2010b, Carbon Trust, 2009a, Energy Technologies Institute, 2010, RenewableUK, 2010a, Douglas-Westwood, 2008, The Offshore Valuation Group, 2010, Sinclair Knight Merz, 2008, Scottish Government, 2010b, Welsh Assembly Government, 2010, DECC, 2011b).

There are fewer European deployment expectation assessments available, however these are shown in Table 25 and Figure 34 below:

Author\Year	Capacity, (GW)			
	2020	2030	2040	2050
EU-OEA (Europe) (Wave)	na	na	na	65.000
Carbon Trust (Europe) (Wave)	1.750	na	na	na
EU-OEA (S1) (Europe) (Marine)	8.000	20.000	66.000	85.000
EU-OEA (S2) (Europe) (Marine)	na	12.000	68.000	85.000

Table 25: Future EU Deployment Models for Both Wave and Marine Renewables (European Ocean Energy Association, 2010, European Ocean Energy Association, 2009, Carbon Trust, 2006)

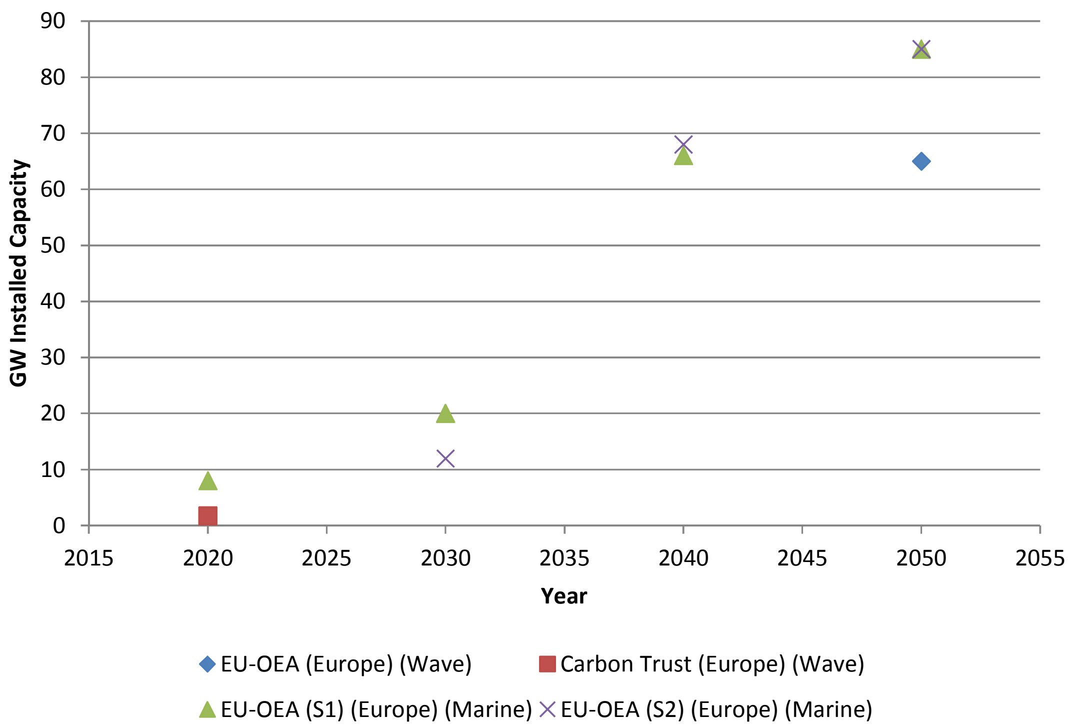


Figure 34: Future EU Deployment Models for Both Wave and Marine Renewables (European Ocean Energy Association, 2010, European Ocean Energy Association, 2009, Carbon Trust, 2006)

Although central government expectations from DECC and the Scottish Marine Energy Group are clearly the most influential in terms of statements of intent to industry, other predictive measures (such as those by RenewableUK for example) give expectations of feasible capacity building, which in turn helps to validate or discredit central government reports.

Marine deployment expectations up until 2020 vary between 0.3-1.5GW capacity range. However by 2050 expectations for capacity diverge even more considerably, and a strong or clear signal of deployment intent is far from evident with only DECC providing any estimation for 2050 from central government.

There are two specific things of note from these figures. Firstly, the Sinclair Knight Merz estimations, which were used as a key capacity reference document in the 2008 UK Renewable Energy Strategy Consultation document, (itself the precursor to DECC's influential UK's Low Carbon Transition Plan) modelled relatively low growth scenarios and this in turn influenced BERR to advise that wave (and tidal) technologies were in their infancy, not ready for commercial deployment and unlikely to generate large quantities by 2020 (Sinclair Knight Merz, 2008, BERR, 2008). Although this is an easily defendable summation, it is a language that could deter potential stakeholders from entering the sector. The second point of note is the 4GW of expected marine capacity deployment from the Welsh Assembly by 2025. Their ministerial policy statement identifies 4GW of wave and tidal stream capacity technical potential for Wales and they present an ambitious 10% capture expectation (Welsh Assembly Government, 2009), twice Scotland's 2020 target. This appears extremely ambitious given their current level of commercial and research activity.

During the primary interview process, the four key government departments, (DECC, Scottish Government, Marine Scotland and the Marine Management Organisation) gave a mean expected wave deployment capacity estimation of 493.75MW by 2020. This is fairly in keeping with the published overall marine deployment estimations as shown above.

6.3.2 Internal Influence upon the Direction of Search:

Internally, the device developers' deployment expectations can be viewed in several ways, however these estimations of their expected capacity were far less optimistic as can be seen from Table 26, Table 27 and Figure 35 below. Of those that gave estimates, (12) the below tables are broken down into national 2020 target estimations based on developer Technology Readiness Levels (TRL) (as described within the Materialisation section of the Methodology Chapter, (5.1.1c)) and on device type respectively.

Device Technical Maturity		Scotland 2020	England/Wales 2020	International 2020
R&D Technology Concept and Application Formulated	Mean	0.00 MW	0.00 MW	0.00 MW
	N	1	1	1
	Std. Deviation	n/a	n/a	n/a
R&D Analytical & Experimental Proof of Concept	Mean	0.00 MW	0.00 MW	0.00 MW
	N	1	1	1
	Std. Deviation	n/a	n/a	n/a
Tech Val. Partial System Validation in Environment	Mean	17.50 MW	0.00 MW	12.50
	N	2	2	2
	Std. Deviation	10.607 MW	0.00 MW	17.678 MW
Tech Val. Sub/System Validation in Environment	Mean	60.40 MW	51.60 MW	70.40
	N	5	5	5
	Std. Deviation	108.124 MW	110.929 MW	109.228 MW
Syst Val. Actual Syst. Demonstrated & Serviced in Environment	Mean	20.00 MW	20.00 MW	150.00 MW
	N	1	1	1
	Std. Deviation	n/a	n/a	n/a
Syst Val. Actual Syst. Proven Through Mission Operation	Mean	550.00 MW	25.00 MW	797.50 MW
	N	2	2	2
	Std. Deviation	212.132 MW	35.355 MW	710.642 MW
Total	Mean	121.42 MW	27.33 MW	176.83 MW
	N	12	12	12
	Std. Deviation	221.406 MW	71.649 MW	368.956 MW

Table 26: Device Developer Deployment Expectation for 2020 by Level of Technical Maturity

Device Type		Scotland 2020	England/Wales 2020	International 2020
OWC	Mean	1.00 MW	2.50 MW	1.00 MW
	N	2	2	2
	Std. Deviation	1.414 MW	3.536 MW	1.414 MW
Semi-Fixed/Fixed	Mean	355.00 MW	0.00 MW	650.00 MW
	N	2	2	2
	Std. Deviation	487.904 MW	0.00MW	919.239 MW
Non-Fixed	Mean	93.13 MW	40.38 MW	102.50 MW
	N	8	8	8
	Std. Deviation	149.593 MW	86.493 MW	118.683 MW
Total	Mean	121.42 MW	27.33 MW	176.83 MW
	N	12	12	12
	Std. Deviation	221.406 MW	71.649 MW	368.956 MW

Table 27: Device Developer Deployment Expectation for 2020 by Device Type

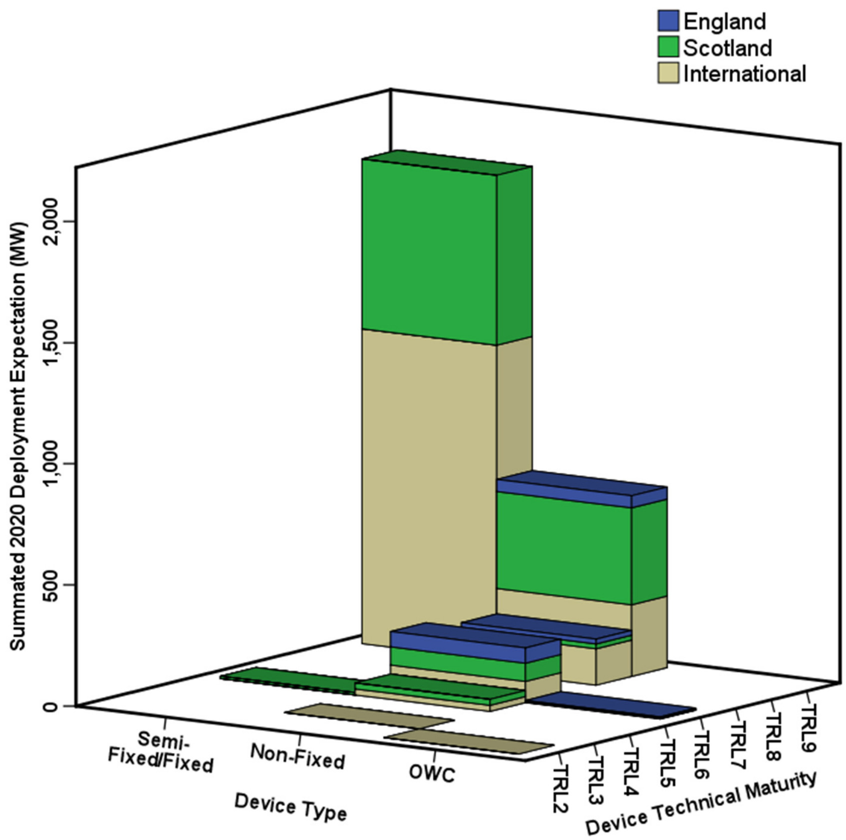


Figure 35: Device Developer Deployment Expectation for 2020

Although there is a high level of variation (standard deviation), there is also a clear expectation among UK device developers that Scotland has a far higher potential for wave energy development. Unsurprisingly, there is also a higher level of deployment expectation among more advanced device developers, (with the exception of the one device developer).

The summated 2020 targets for deployment from all interviewees was 328MW of capacity for England/Wales and 1.457GW for Scotland. This gives a total deployment expectation in Great Britain of 1.785GW and an international (worldwide) deployment expectation of 2.12GW. Bearing in mind that this is for wave energy deployment only and that it excludes deployment expectations from 3 non-respondent wave energy companies, this can be considered a higher target expectation than most government and policy documents forecast (excluding Wales' target).

When assessed against technology type, it is clear that despite higher numbers of non-fixed device developers, there is a higher deployment expectation among the fixed/semi-fixed device developers.

For 2050 targets, device developers were more reluctant to give a deployment expectation, however the responses of the seven that did answer are summarised in Table 28 and Table 29 below:

Device Technical Maturity		Scotland 2050	England/Wales 2050	International 2050
R&D Technology Concept and Application Formulated	Mean	0.00 MW	0.00 MW	0.00 MW
	N	1	1	1
	Std. Deviation	n/a	n/a	n/a
R&D Analytical & Experimental Proof of Concept	Mean	0.00 MW	0.00 MW	0.00 MW
	N	1	1	1
	Std. Deviation	n/a	n/a	n/a
Tech Val. Partial System Validation in Environment	Mean	350.00 MW	0.00 MW	400.00 MW
	N	2	1	2
	Std. Deviation	353.553 MW	n/a	565.685 MW
Tech Val. Sub/System Validation in Environment	Mean	610.00 MW	25.00 MW	10210.00 MW
	N	5	4	5
	Std. Deviation	1077.265 MW	50.00 MW	22247.371 MW
Syst Val. Actual Syst. Proven Through Mission Operation	Mean	4500.00 MW	0.00 MW	45000.00 MW
	N	1	1	1
	Std. Deviation	n/a	n/a	n/a
Total	Mean	825.00 MW	14.29 MW	9685.00 MW
	N	10	7	10
	Std. Deviation	1502.452 MW	37.796 MW	19968.448 MW

Table 28: Device Developer Deployment Expectation for 2050 by Level of Technical Maturity

Device Type		Scotland 2050	England/Wales 2050	International 2050
OWC	Mean	25.00 MW	50.00 MW	25.00 MW
	N	2	2	2
	Std. Deviation	35.355 MW	70.711 MW	35.355 MW
Semi-Fixed/Fixed	Mean	2300.00 MW	.00 MW	22500.00 MW
	N	2	1	2
	Std. Deviation	3111.270 MW	.	31819.805 MW
Non-Fixed	Mean	600.00 MW	.00 MW	8633.33 MW
	N	6	4	6
	Std. Deviation	969.536 MW	.000 MW	20270.340 MW
Total	Mean	825.00 MW	14.29 MW	9685.00 MW
	N	10	7	10
	Std. Deviation	1502.452 MW	37.796 MW	19968.448 MW

Table 29: Device Developer Deployment Expectation for 2050 by Device Type

Compared with the government and other stakeholder estimations (shown in Table 24 above), the sum total of deployment expectations by 2050 as predicted by device developers (calculated by multiplying the average prediction with the number of overall respondents) within Scotland is around 8.25GW, for England 0.1GW and internationally, 96.85GW. The standard deviation however for these figures is extremely high and thus there is high a level of variation to this data. This is significantly higher than current public statements. England/Wales' 2050 deployment is in fact less than its 2020 expected target, however this is due more to a lower level of respondents. If the mean average values for deployment are taken for all scenarios and multiplied by the number of wave energy companies within the UK, (i.e. both respondent device developer companies and non-respondent device developer companies) the deployment expectations are as shown in Table 30 below:

Number of Device Developers:	
Respondent	14
Non-Respondent	3
Total:	17

Mean Deployment Values:	2020 (MW per-developer)	2050 (MW per developer)
England/Wales	23.33	14.29
Scotland	121.42	825
Internationally	176.83	9685

Interpolated Deployment Values	2020 (GW total)	2050 (GW total)
England/Wales	0.40	0.24
Scotland	2.06	14.03
Internationally	3.01	164.65

Table 30: Interpolated Device Developer Deployment Expectations for 2020 and 2050

The primary interview stage offered a unique opportunity to ask device developers, utility companies and universities (in question 4(b)) why they entered into the sector. This would provide a qualitative validation for the overall market entrance of stakeholders which could help to explain market entrance/exit trends. The results from 30 respondents (13 device developers, 5 utilities and 12 universities) are provided within Figure 36 which shows the percentage of stakeholders who identified the categorised reason as one for entering into the sector, (respondents were allowed to choose more than one reason). The relative average percentage represents a normalised average removing the total respondent weighting for different stakeholder types, (i.e. weighting average device developer, utility and university responses equally).

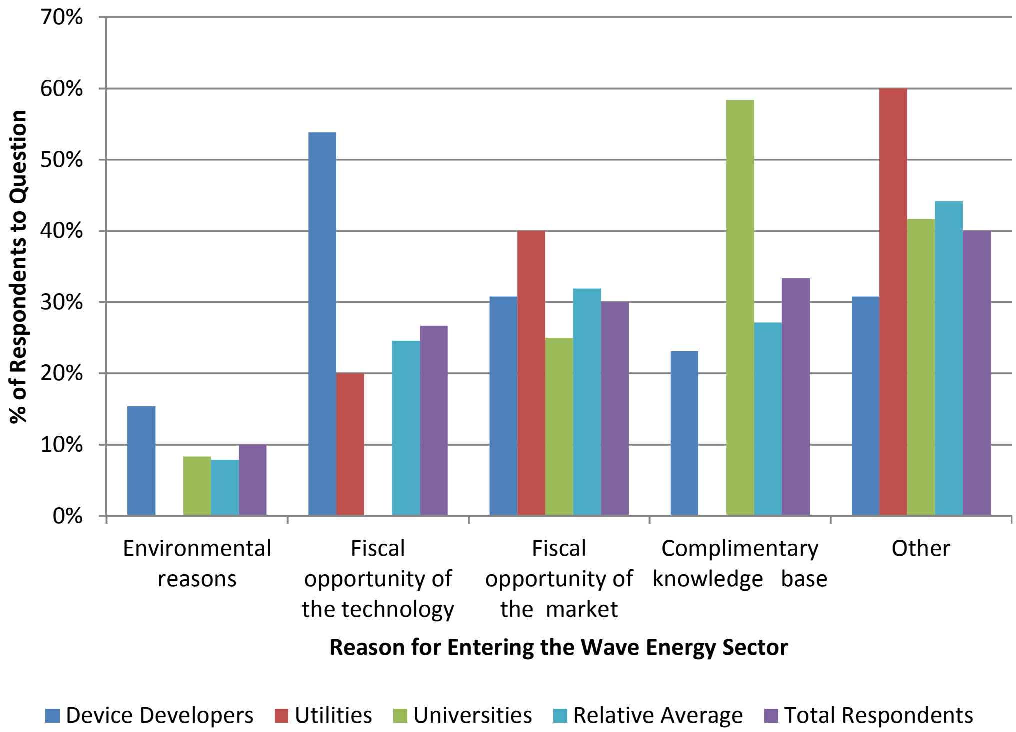


Figure 36: Stakeholders Reasons for Entering into the Wave Energy Sector

Figure 36 shows that most stakeholders within the respondent population included reasons other than those categorised (40%), however due to the large number of universities interviewed; complementary knowledge came second (33%) overall and was clearly the main single reason within university institutes (58%). In contrast to this, the economic opportunities of the technology were clearly the primary single reason for device developers to enter into the sector (54%). Interestingly, environmental reasons were only mentioned by 10% of all interviewees validating the argument that the reasons for commercialisation of the wave energy sector are clearly more commercially focussed than the early renewable innovation systems such as the Danish wind industry in which a grass-roots environmental movement greatly assisted in maturation of the technology (Karnøe, 1990).

6.3.3 Investors Influence upon the Direction of Search

In 2010, DECC commissioned Kreab & Gavin Anderson to question twenty one investor institutes regarding their expectations of the wave energy sector. This included banks, corporate investors, venture capitalists and angel investors who were working within the renewable sector (some within marine renewables)(Walter, 2010). The presented findings of this study showed that sixteen were positive about the marine energy sector, three were neutral and two were negative. For existing investors within the sector, inadequate levels of funding were seen as the largest specific issue, however with potential investors who were not working within the sector, the technology reliability itself seen as the largest concern while 'Funding' was surprisingly seen as the third largest issue behind 'Management'. This is somewhat surprising as it suggests that those investors outside of the system currently perceive finance to be not as large an issue as do those that are already within the sector (Walter, 2010)(See Investor Legitimacy, section 6.6.3 within this chapter for more information).

6.4 Materialisation

The function of materialisation in the context of the UK wave energy sector is simplistically the level of UK MW deployment that has occurred and the levels of technical maturity that device developers have managed to accomplish.

Although this does provide critical insight; without an international scope for UK companies' levels of deployment, an assessment of how much learning by doing or the levels of appropriate manufacturing readiness (i.e. 'up-scaling' of manufacturing capabilities) cannot be critically evaluated. For this reason therefore, levels of global deployment by UK companies shall also be assessed along with levels of UK deployment by non-UK based companies, (since this clearly also provides insight into how much UK market activity has occurred).

If the 'Influence on the direction of search' is a measure of the industry's future expectations, materialisation is the current level of deliverance upon prior expectations.

6.4.1 Current UK Deployment

as of April 2011 there was an installed level of capacity within the UK of 1.31MW, comprising: Voith Hydro Wavegen's Limpet (0.25MW), Aquamarine Power's Oyster 1 (0.315MW) and from Pelamis Wave Power's Pelamis 2 system (0.75MW) (RenewableUK, 2011). Although Voith Hydro Wavegen is now owned by the German company Voith Siemens Hydro (following a 2005 acquisition), it continues its main R&D operations within the UK. Both Pelamis Wave Power and Aquamarine Power are UK owned Scottish companies (both with international major share holders).

6.4.2 UK Planned Deployment

From 2011 onwards deployment, looks set to ramp up at EMEC and other locations, including Wave Hub's first deployment from OPT. Although future deployment is covered in greater depth in the 'Influence Upon the Direction of Search' section of this chapter (6.3.1), some current planned instalments are being manufactured for deployment. These current and near future deployments are highlighted shown in Figure 37 below.

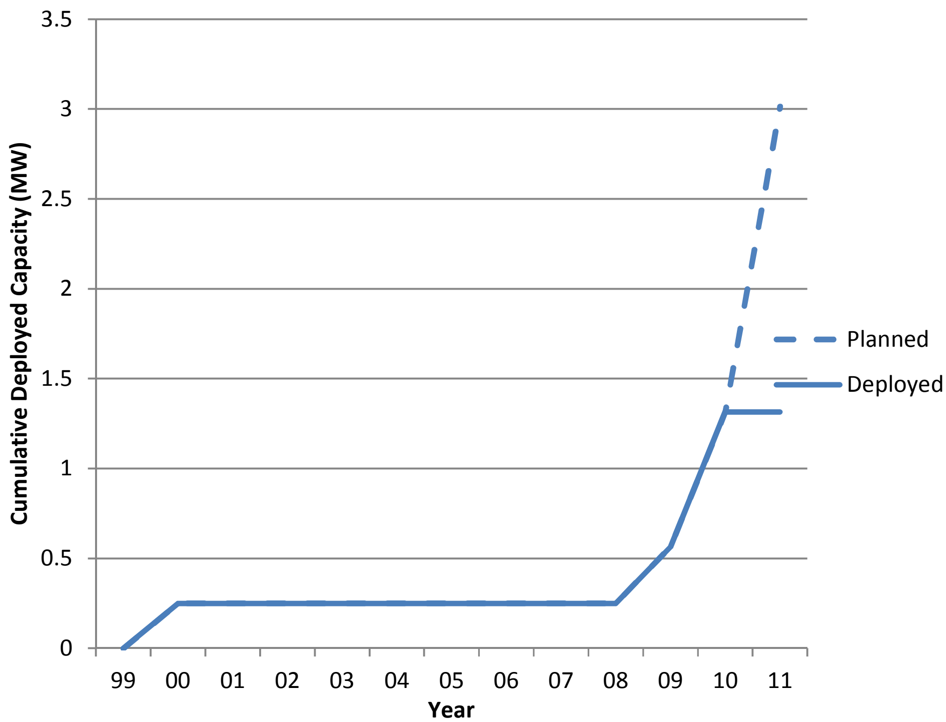


Figure 37: UK Wave Energy Deployment

6.4.3 Non-UK Deployment

Internationally, there has only been one commercial deployment by a UK based company, Pelamis Wave Power Ltd's offshore installation at Aguçadoura in Portugal. This commercial site comprised of 3 x 750kW rated Pelamis (P1) devices but was only in operation for 2 months, (from September till November 2008). There were multiple reasons for its closure: Firstly technical problems with the device meant that it required some re-engineering of both the buoyancy tanks and hydraulic systems. Also the project's 77% share holder (the Australian firm

Badcock and Brown), went into administration soon after the project began (due to un-related financial problems) (Cleantech Group, 2009).

6.4.4 Technology Readiness Levels

The levels of technology readiness that were reported by respondent interviewees to question 2(a)), is shown in Figure 38 below:

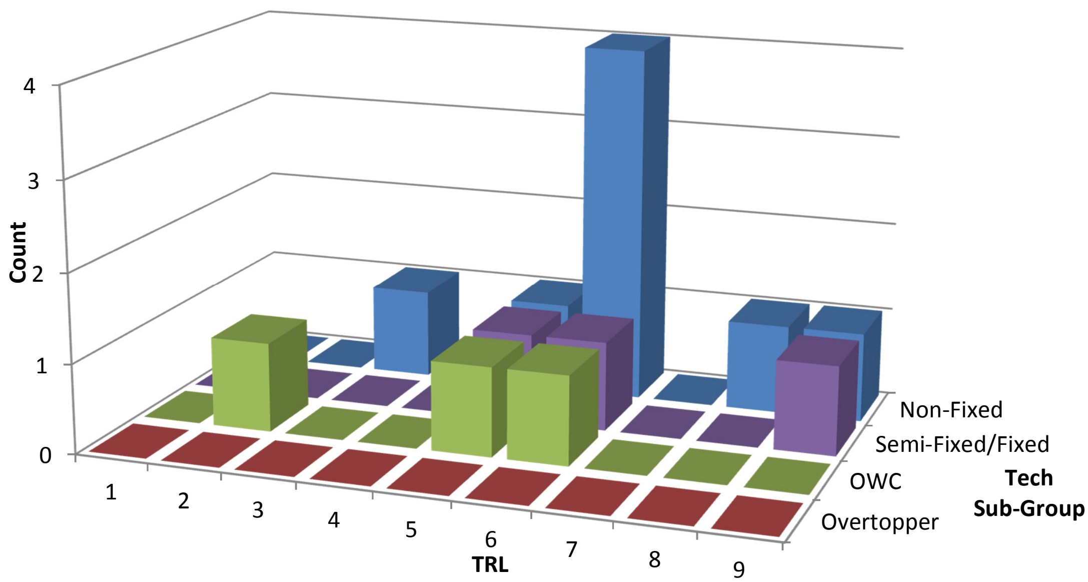


Figure 38: UK Wave Energy Developer Technology Readiness Levels

As can be seen, there is a 'clustering' of devices around technology readiness level 6, which is equivalent to system/subsystem model validation in a relevant environment, (such as a scale test facility like NAREC). This is considered to be the last of the applied research stages before prototype demonstration and system validation commences. It is also the stage at which the costs of R&D become far higher as larger manufacturing techniques are required with proof of concept and pre-prototype testing costs estimated at between £500k<£5m and full scale prototyping costs are estimated at up to £10m (Scottish Government, 2010b, EG&S KTN, 2010).

"The Government have to say; 'Yes, some of these (devices) we're going to back will fall by the wayside' but if they put £50m, into 5 devices, over 5 years, we would have some units in the water producing electricity."

Device Developer

At this point of technology readiness, (i.e. pre-full scale prototype manufacturing) the only current (as of 04/04/11) public funding scheme that will provide investment for wave energy technology towards TRL7 is the Carbon Trust's Applied Research Grants, and this funding is limited to relatively small £0.25m per applicant. All other relevant funding schemes, (most notably the MRPF and Scottish WATERS programme) have been closed to new applications, creating a bottleneck (or 'gating' depending upon perspective) of developers at pre-validation stage attempting to find private finance.

6.5 Knowledge Generation

6.5.1 Patents

6.5.1a UK Wave Energy Patents within Context

Patents play an enormous and important role within the creation of a new technology sector such as the wave energy sector. They underpin much of the external and private investment and thus act as the driving impetus for much of the entrepreneurial activity that occurs within device developer and other small innovator companies. Almost all device developer respondents believed that this was the case as can be seen from responses to the question on the perceived value of patenting shown in Figure 48. Without patents (and the security of intellectual property they represent) there would simply be no venture funding and device developers as investors would have no guarantee that the device that they were investing in would be able to secure a return without others imitating or even improving upon the original design.

6.5.1b World Patent Statistics

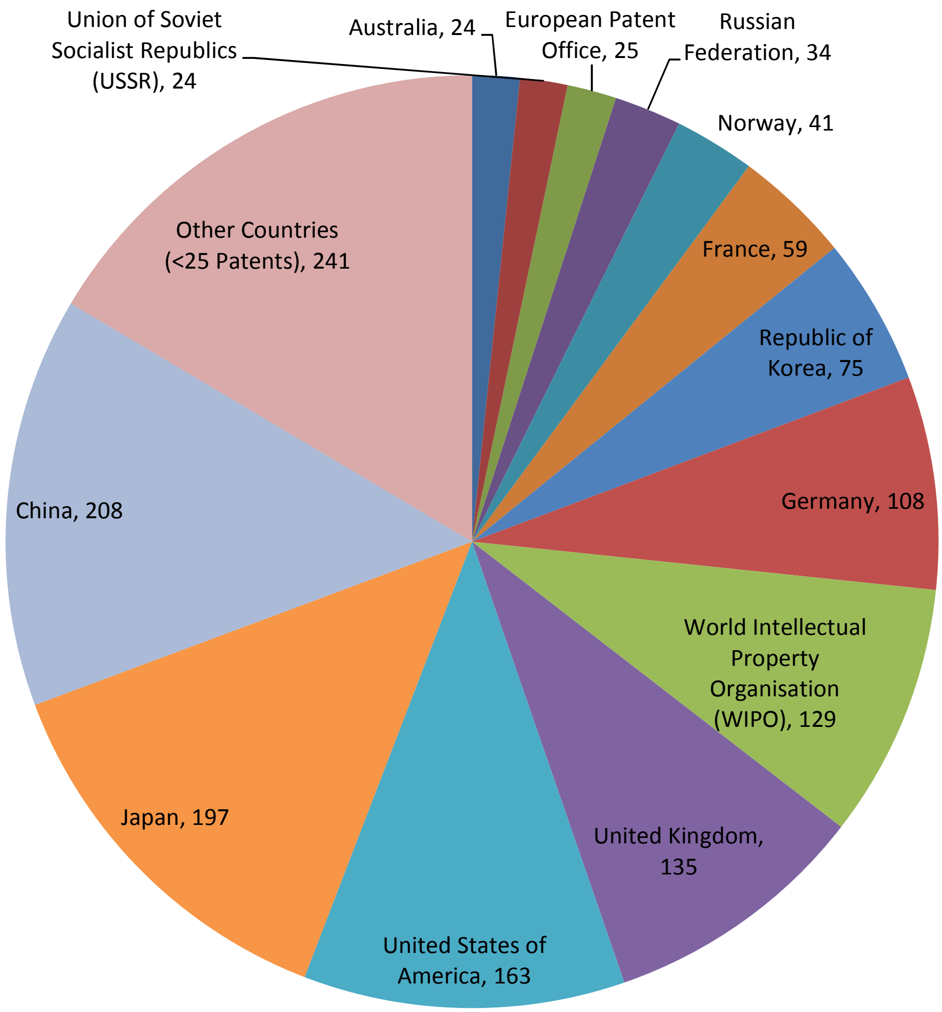


Figure 39: Breakdown of World Wave Energy (F03B13/14 only) Patents Published Since 1900 (By Country)(European Patent Office, 2010)

Figure 39 shows that for F03B13/14 wave energy only patents only, (i.e. those unspecified by other patent classifications) China has the largest individual country percentage of patents followed by Japan, the USA and then the UK.

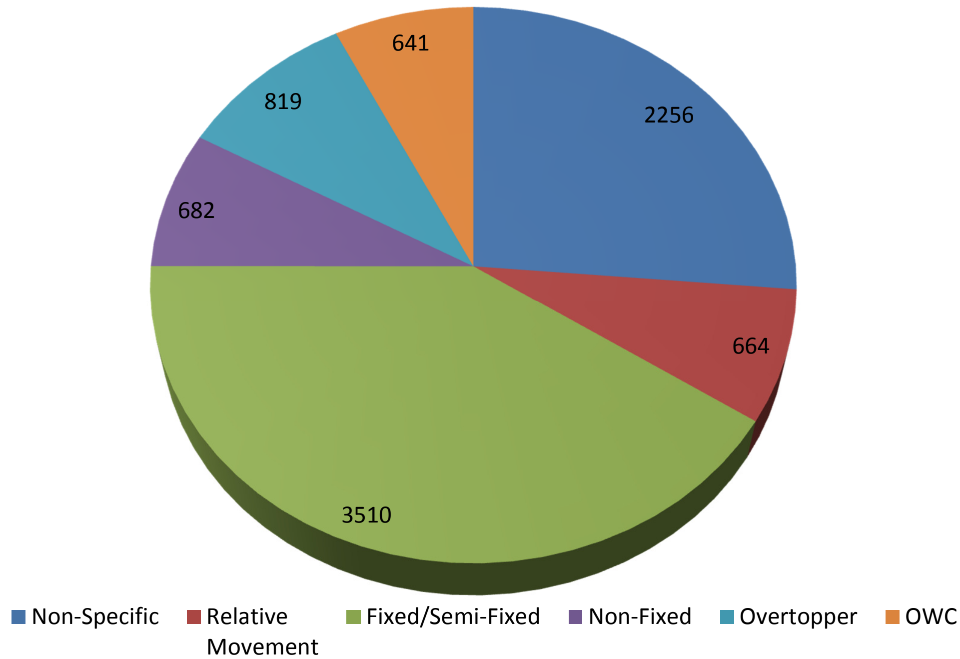


Figure 40: Total World Wave Energy Patents by Classification (European Patent Office, 2010)

Globally, there have been over 8500 patents since 1900 filed specifically for wave energy devices, (this figure may seem high but for comparison, there are over 3000 F03G7/10 patents classified as 'Alleged perpetua mobilia devices' and over 15000 H01L31/00 patents classified under the solar photovoltaic devices designation (European Patent Office, 2010). Within the same, fixed and semi-fixed devices dominate the worldwide patent classifications, however, surprisingly, non-fixed devices which are required for deepwater deployment (such as the current UK market leading, Pelamis and Powerbuoy devices) only represent a small fraction with a total of 682 patents.

6.5.1c GB Patent Statistics

		World Patents:	UK Patents:	UK % Comparison to World Average
F03B13/14	Non-Specific	2256	135	90%
F03B13/16	Relative Movement	664	15	34%
F03B13/18	Fixed/Semi-Fixed	3510	267	115%
F03B13/20	Non-Fixed	682	80	177%
F03B13/22	Overtopper	819	25	46%
F03B13/24	OWC	641	47	110%
Total:		8572	569	100%

Table 31: Patent Summary and Patent Type Ratio for UK compared to the World

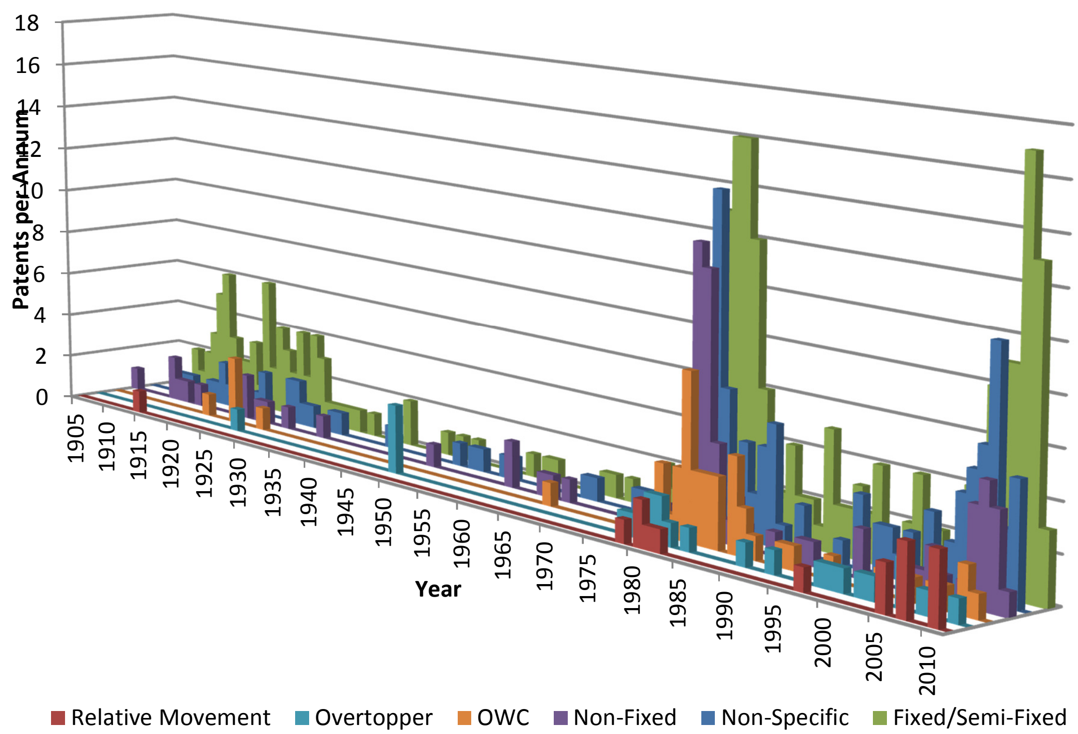


Figure 41: Number UK Wave Energy Patents Published Per Year (European Patent Office, 2010)

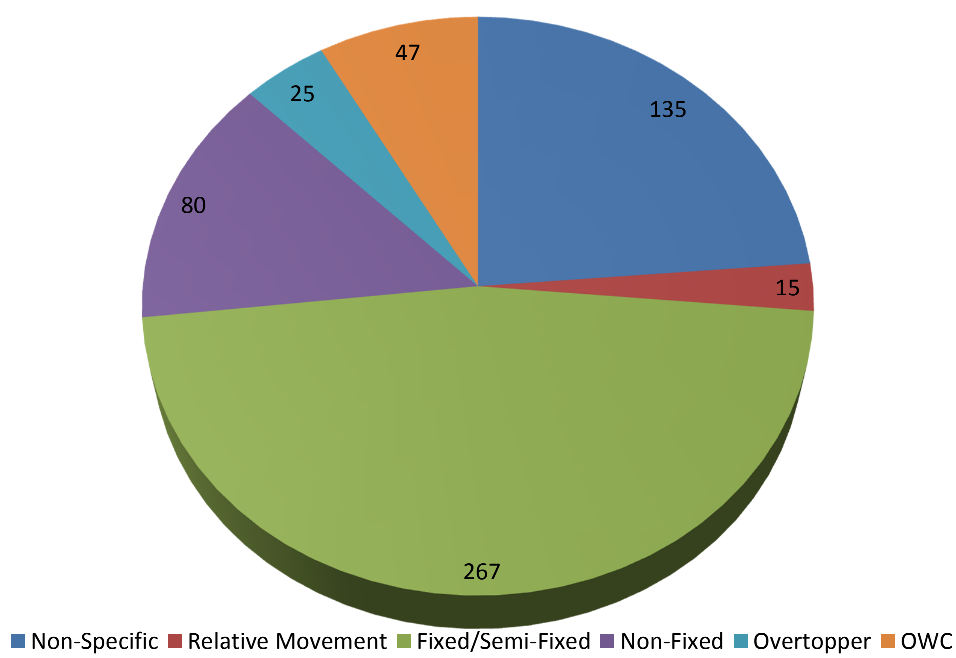


Figure 42: UK Wave Energy Patents Published Since 1905 (European Patent Office, 2010)

Within the UK, patenting culture seems similar to that of the world distribution of classifications, again with semi-fixed and fixed device patents holding almost 50% of the distribution.

'Relative Movement' machines are low in representation at only 15 patents (or 34% of the global average) one explanation for this could be that their classification category conceptually overlaps with other device types (i.e. all relative motion machines are either fixed or non-fixed and almost all non-fixed machines have relative motion). Given their overall internal expectation of legitimacy for this type of technology (See Legitimacy section within this chapter (6.6.5)) it seems in keeping that non-fixed devices represent a higher level of patenting (177% above the global average give the total number of UK patents) and this is in part explained by the fact that two of the current lead technologies (the Pelamis system and Powerbuoy) are non-fixed devices.

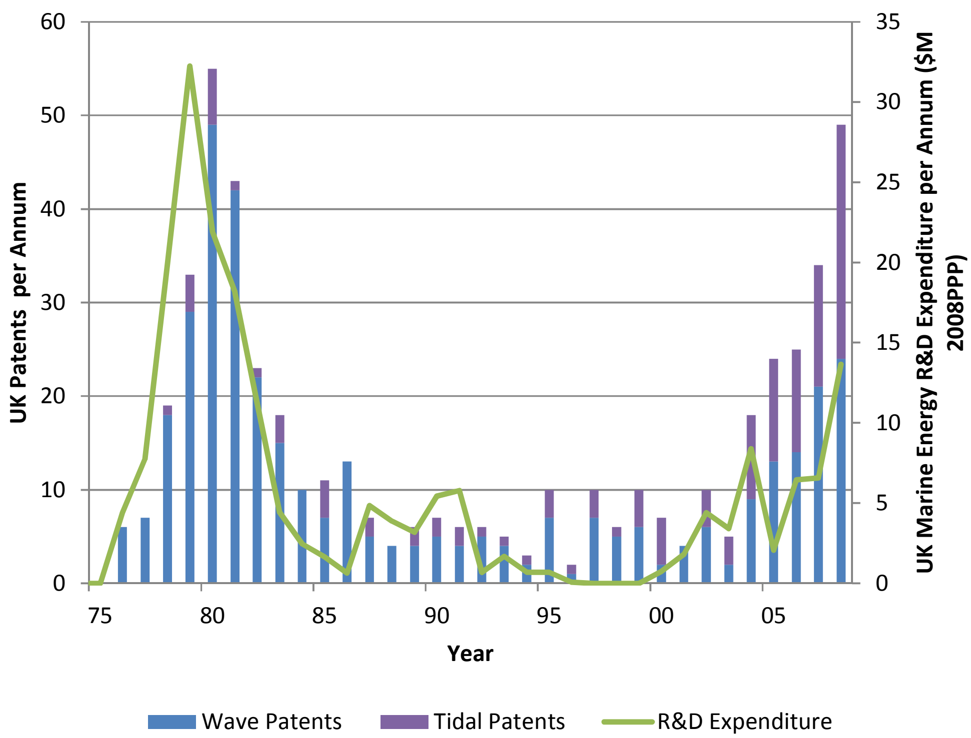


Figure 43: GB Marine Energy Research Expenditure and Patents Since 1974 (IEA, 2010, European Patent Office, 2010)

Figure 43 shows that there is a clear correlation between patenting activity within the UK and the amount of R&D spend over the past few decades. This is are in line with what would be expected in that historically during the mid-70s there was a large level of public interest in wave and tidal technology, falling in the 80s and being re-initiated from the start of the 21st century.

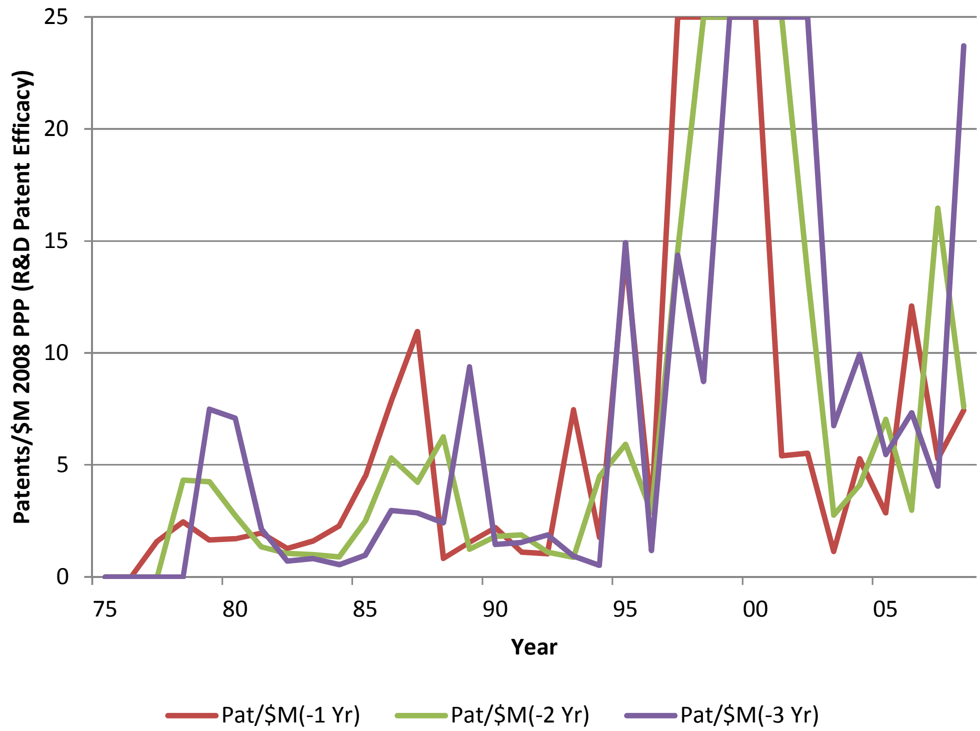


Figure 44: UK Marine Energy Patent Efficacy Measures (Patents per $M)

Efficacy of R&D spend (using patents as the primary indicator) can be assessed by measuring patents/$M spend. however there is an expected lag time from when funding goes into the sector to when a patent is applied for plus the 'priority year' - from patent application to acceptance and then publication (OECD, 1994).Figure 44 shows the number of patents per $M spent with 1, 2 and 3 year lag times from spend to patent publication. As can be seen, the Pat/$M-2Yr curve shows an overall smoother profile that that of either -1Yr or -3Yr which implies a more accurate account of fit (either this or patent efficacy fluctuated in such as way that the -1 and -3 year data sets are similar in profile however un-related which is clearly unlikely). Efficacy from the mid-90s to around 2003 is deceptive as ocean energy public R&D spending was so low (see Figure 43) that singular patents over this time would have skewed the data. There was nonetheless an increase of patents for both the non-specified and semi-fixed patent subgroup over this period. Another interesting point to note is the increase in efficacy over the last 5 years in comparison to the 80's and early 90's where efficacy rarely rose above 5 patents per $M. This almost certainly is the result of an overall increase in patenting culture as a society, (Kortum and Lerner, 1999) but may also be accounted for in the more applied research that is now being conducted as the sector moves from a primary research phase into a commercially orientated position.

Finally, the average efficacy of resident patents filed (within the UK) per $M from 1997 to 2007 is shown in Figure 45 below. This equates to an average of 0.7 Pat/$M over the 11 year period (World International Patent Office and UNESCO, 2009). Comparing this with the average marine energy patent efficacy of 8.09 within the UK for the same period shows that by national standards, the marine energy sector is still extremely patent rich.

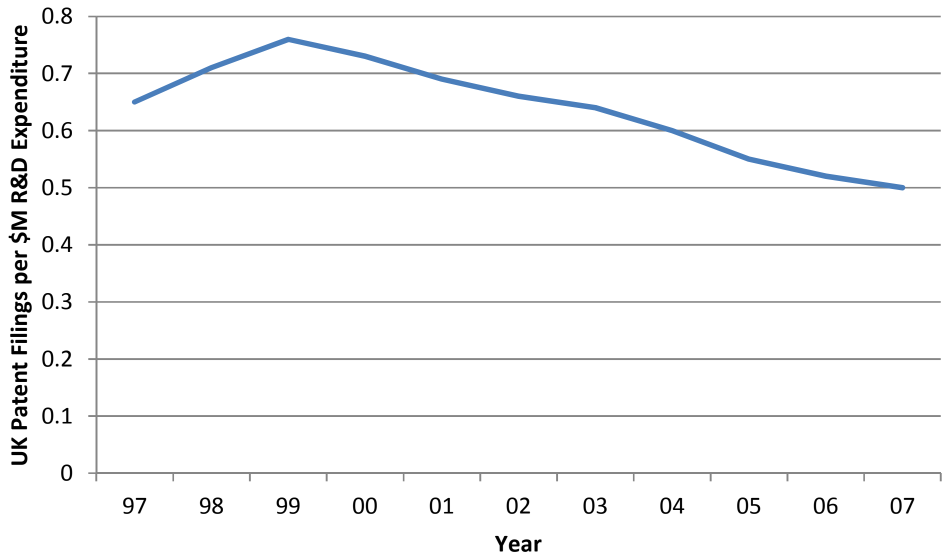


Figure 45: Average UK Patent Filings per M$ R&D expenditure

6.5.1d Primary Study Statistics

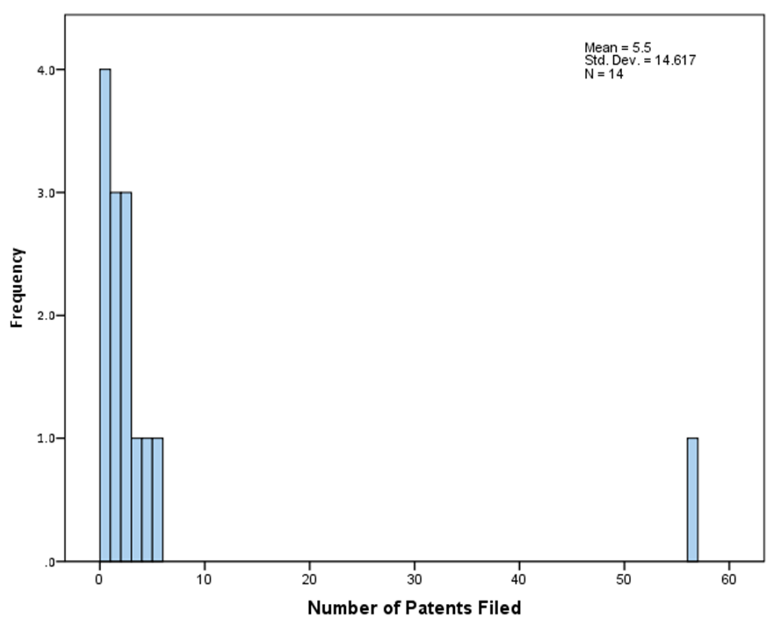


Figure 46: Number of Patents Filed (For Device Developers Only)

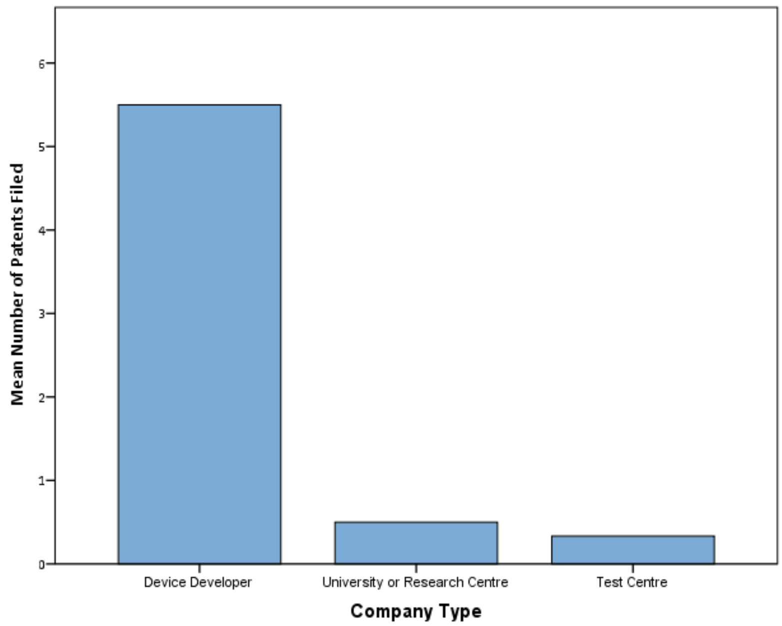


Figure 47: mean Number of Patents Filed

Among the interviewees it is clear, (as would be expected) that on average, device developers hold a larger number of wave energy patents than both universities or test centres - who, (on average) hold less than one wave energy patent per institute. Device developer data is skewed somewhat by the fact that one device developer has a very strong patent culture, holding over 50 patents specifically for main and sub-components within the design of the device (see Figure 46). Excluding this one device developer, the mean value drops to 1.6 patents per device developer, still around three times more than academic and/or research centres and far more than test centres.

It is not unsurprising that test centres have a low patenting culture as regards wave energy devices, as this could clearly be seen as a conflict of interest for those who would use the test centre with their own devices.

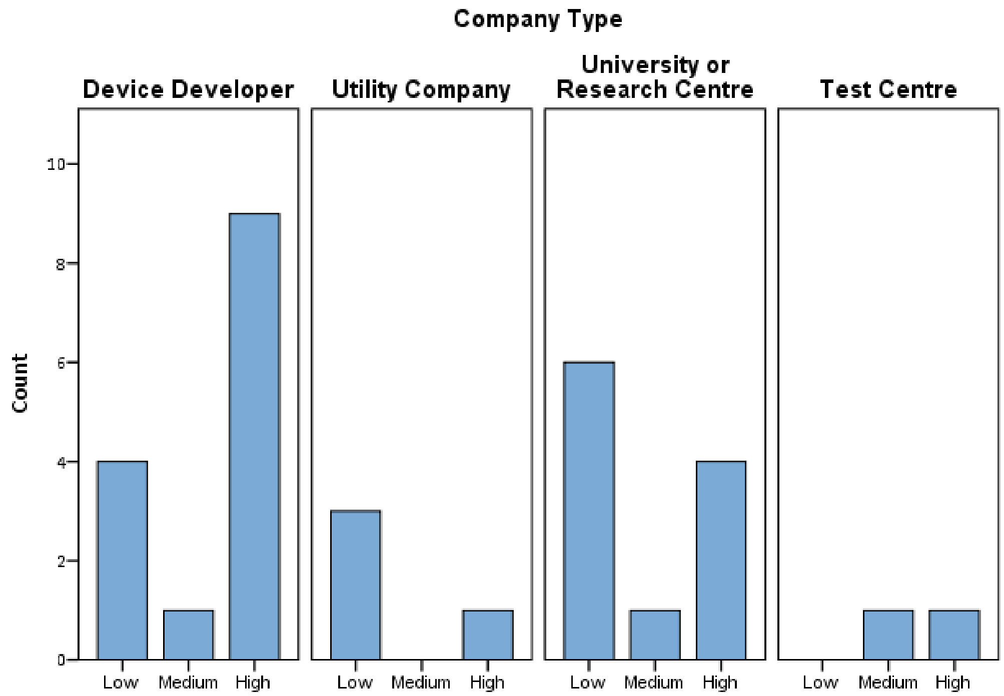


Figure 48: Perceived Value of Patenting

Figure 47 results are complemented by the perceived value of patenting scores shown in Figure 48. Device developers clearly have a higher overall perceived value of patents than any other grouping (as both an absolute number but more importantly as a ratio). Interestingly, of the 11 university respondents to this question, 6 had a low perceived value while 4 had a high and only one, medium. This was perhaps due to the type of research being conducted as, of the 4 universities that had a high perceived value of patenting, 2 had previously designed wave energy devices and so clearly had some sense of applied commercial acumen to their research. Many of the others however were focussed on more 'generic' technological development such as standards, modelling techniques and environmental baseline studies.

Another finding of interest is that utility companies generally perceived the value of patenting to be quite low. From qualitative discussion, it was found that this was primarily due to the fact that utility companies involved within the sector perceived themselves as purchasers and users of technology not technology innovators. This was contrary to what some smaller device developers believed was or should be the case, many suggesting that it should be the '*social responsibility*' of utility companies to assist in the commercial development of the sector through technology development and financial assistance rather than project development.

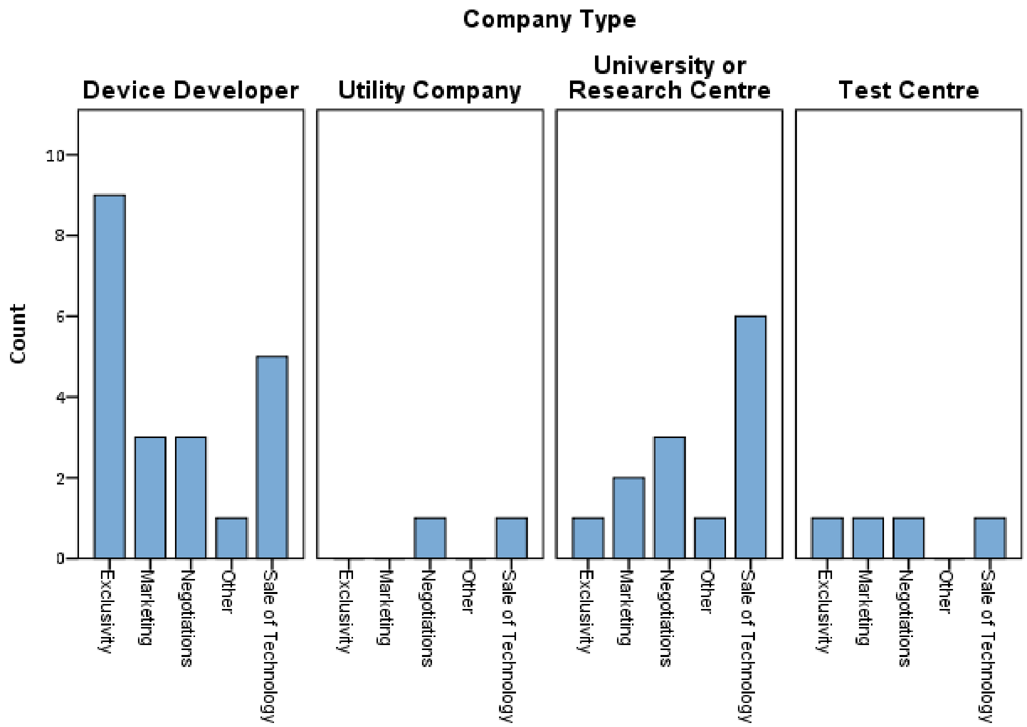


Figure 49: Reason for Patenting

Respondents to question 1(g) on the reported reasons for patenting were allowed to select multiple answers. Figure 49 shows that within device developers, exclusivity and sale of technology were seen as the key reasons for patenting. What is possibly more surprising is that only 64% of developers (with 0 non-respondents) reported 'exclusivity' as a main reason for patenting. There were another five who would actively seek the idea of technology sales transfer, which implies that there is clearly scope for technology licensing or patent pooling approaches to be applied within the UK sector. This is more evident within universities whose primary commercial reason for patenting was for the purpose of technology sales transfer itself. Additionally, three universities reported that patents were valuable for assisting with negotiations, specifically with device developers, where they could provide unique technical assistance based upon their patented technical facilities or services.

> "With wave energy, one of the big issues is device control and for that you don't really need to patent because it's pure IP and it's locked away so you don't need to shelter behind a patent."
>
> University

Although not one of the written questions, most universities claimed to have some form of broad intellectual property board or group who would review potentially patentable or licensable technological inventions when identified, to ascertain if commercial spin-out could be viable. The level of coupling between the academic researchers, the various Intellectual

Property Rights (IPR) review boards and the wider marine renewable industry however (as a potential customer) was not clear in many instances and clearly varied from institute to institute.

Most university-developer relationships had an element of innovative 'blinkering' in that there was a level of 'relationship lock-in' built from a historic legacy of collaboration that created a high level of social capital between the two institutes (and thus lower transaction costs etc. (Walker *et al.*, 1997)), as well as in some cases a lack of wider actor knowledge within the sector.

This somewhat prohibited device developers from searching elsewhere and thus universities from 'selling' any applied research to other developers. There was also a feeling among device developers that, should they encounter a technical problem, their search heuristics for a solution would not be to contact universities working within the sector to see if solutions were currently available. This may be unfortunate given the high value placed upon patent sales by universities. Given this 'chicken-egg' deadlock, some form of centralised but third party managed patent pooling system (managed by an intermediary such as the TSB, CT or UKTI) might potentially provide a solution that could help to overcome both the effort and (currently lacking) appropriability required for device developers to search for an 'outside' solution for technical problems.

All respondent device developers from primary interviews suggested that they would (finances permitting) patent important, genuinely novel or key inventions with consideration for the cost of patenting. Many other inventions would nonetheless be regarded as 'hidden inside the final design' and thus neither patented not exploitable individually (such as through technology sales or licensing). In this respect there was an acknowledgement of what is referred to as the appropriability of the technology (i.e. it's 'hidden nature' which could be as software or simply embedded within a device that was very unlikely to be seen by persons outside of the company) kept it from being exploited by potential competitors (Dosi *et al.*, 2002).

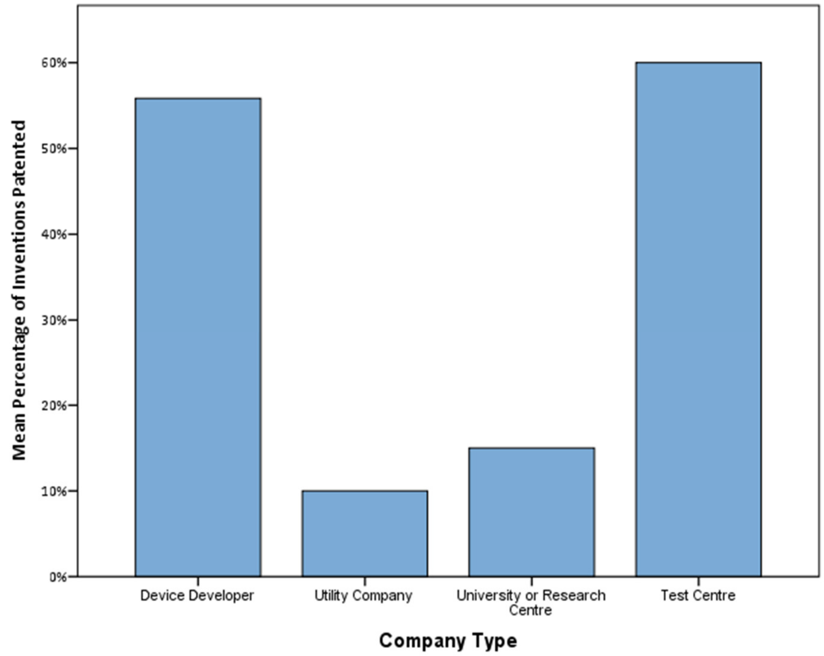


Figure 50: Estimates on Number of Inventions Patented

As can be seen from Figure 50 in response to question 1(g) (what percentage of inventions does your organisation patent?), test centres reported patenting the highest proportion of inventions despite only holding a low number of average patents. Device developers on average reported that around half of all inventions were patented while within universities (and utility companies), this figure was far lower at between 10% and 15%. Other than the test centre statistic, these figures seem expected as universities clearly have a lower average perceived value of patents whereas device developers placed higher value on applied commercial knowledge, (i.e. the workings of their devices).

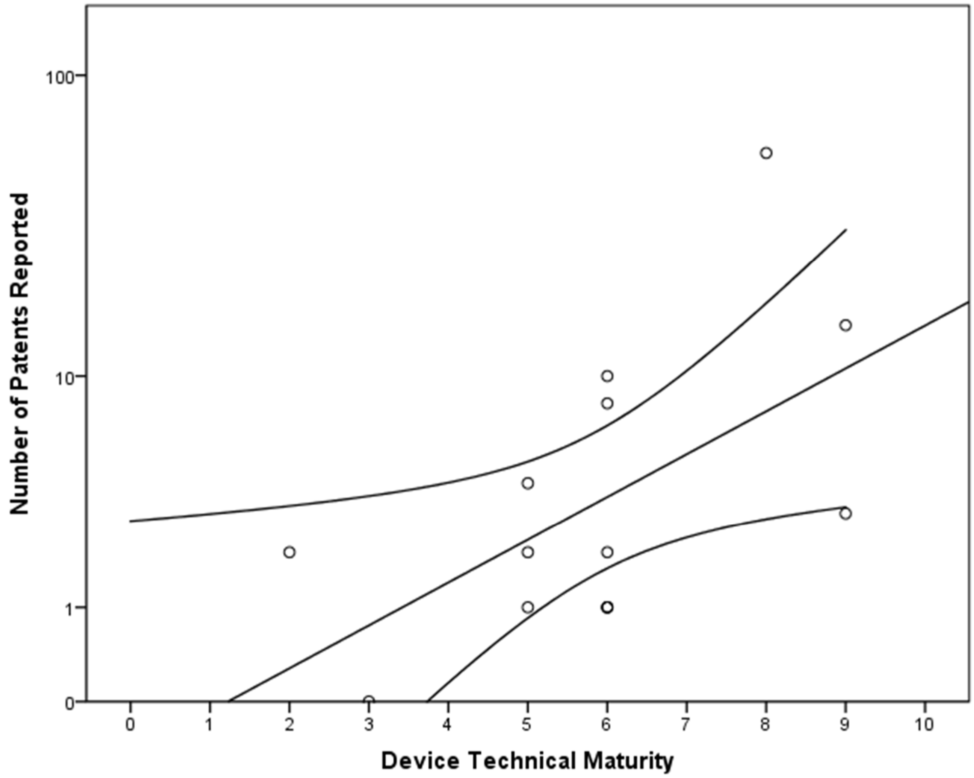


Figure 51: Patents to Device Maturity Table (with 95% confidence line of fit)

> "What we did do very earlier on was to patent the key aspects and spend quite a large chunk of the funding we'd managed to attract at that time to do that because the only reason that people will invest in a technology company is if they are secure that that technology is able to be protected, defended and exploited."
>
> Device Developer

It can be seen from Figure 51 that there is a direct linear relation between patents filed and device technical maturity within developer companies. This correlation is significant (to <.01 for one-tailed correlation using Kendall's τ). This finding is not particularly surprising given that more mature technology developers have on average higher levels of funding available and more refined technology solutions.

What this does show however is that if technology maturity is used as indicators for innovativeness within the sector, then patents represent a strong indicator of innovation among device developers companies with reference to their technology. This is clearly only applicable to applied commercial knowledge and still fails to show innovation within more generic research techniques or understandings as well as regulatory or institutional innovations for which patents themselves are a poor indicator.

6.5.2 Experience Curves

Experience curves are considered a strong indicator for the knowledge generation occurring within a sector (Hekkert *et al.*, 2007). Within the UK Marine energy sector there have been several attempts to map learning curve rates for wave energy technology. Most recently by DECC (Figure 52), the Carbon Trust (Figure 53) UKERC with the ETI (Figure 54) and RenewableUK (Figure 55) all shown below:

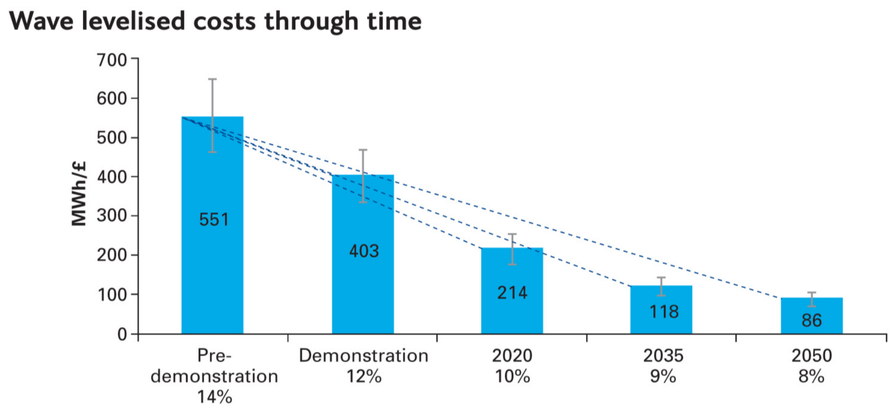


Figure 52: DECC's Wave Energy Cost Estimation (DECC, 2010b)

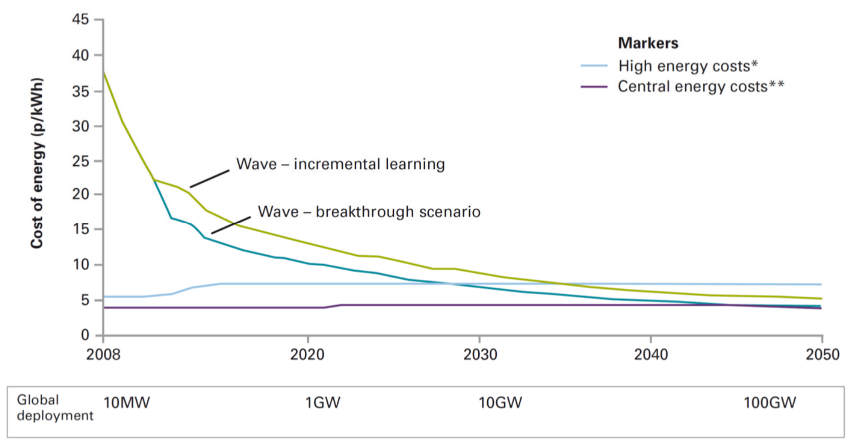


Figure 53: Carbon Trust's Wave Energy Cost Estimation (Carbon Trust, 2009a)

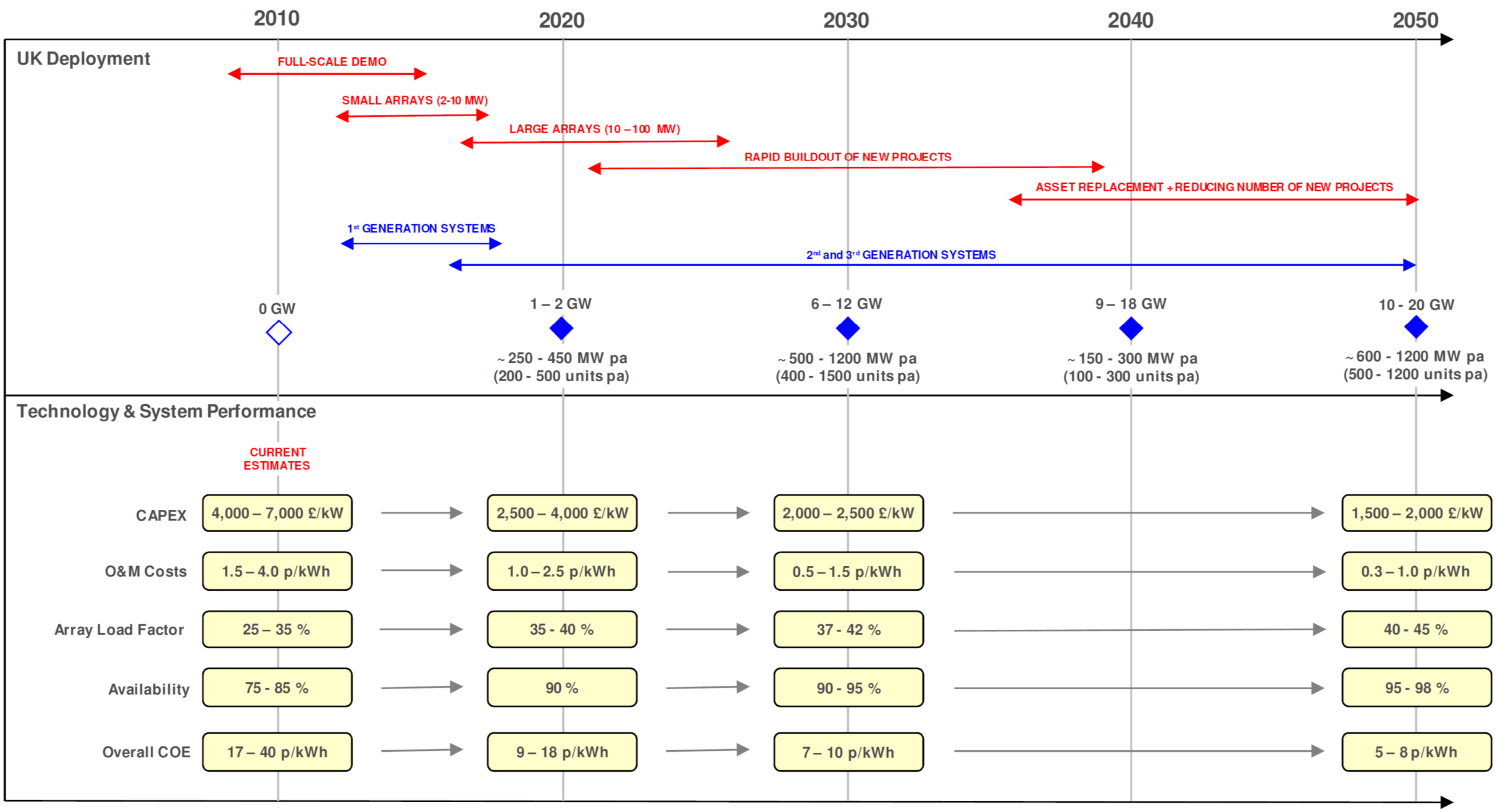


Figure 54: ETI/UKERC's Wave Energy Cost Estimation (Energy Technologies Institute, 2010)

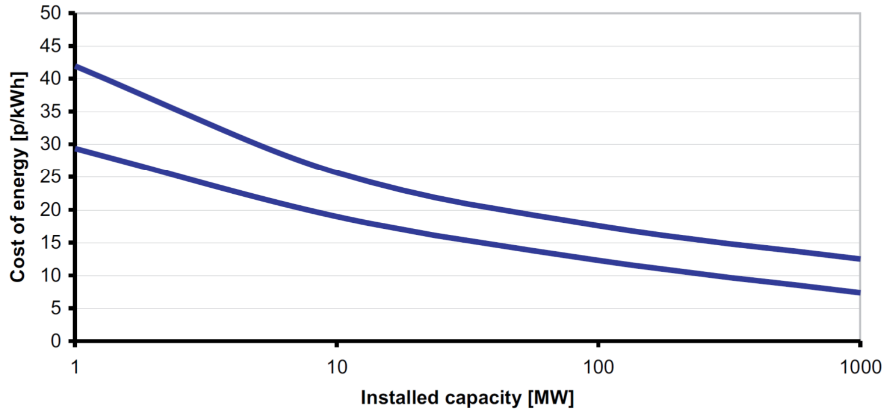


Figure 55: RenewbleUK's Wave Energy Cost Estimation (Entec UK Ltd, 2009)

As can be seen from the various cost curves above, cost estimations for initial wave and marine renewable energy technologies ranging from as high as 55.1p/kWh (DECC, 2010b) to as low as 17p/kWh (Energy Technologies Institute, 2010). This wide range in costs is a result of:

- A wider *range of devices* and therefore high uncertainty as to the range of initial manufacturing costs for differing technologies (i.e. a high mean levilized costs kurtosis).
- A wide *range of maturities* of device development and therefore high uncertainties as to the comparability of different technologies.
- A wide *range of sites available* for differing technology types as well as the differing associated costs, (i.e. onshore, near-shore and off-shore) and therefore high uncertainties as to the individual project costs of deployment.
- *A lack of scale deployment experience* and therefore high uncertainty as to the experience curve cost reduction rate.
- Poor levels of clarity when producing experience curves and cost reductions in terms of both modelling parameters, (such as discount rates applied) as well as assumptions made (such as technology type or deployment rate for starting estimations. This point was highlighted by Stallard et al. in a recent conference paper on economic assessment of marine energy (Stallard *et al.*, 2009).

It is also very difficult to make technology learning estimations regarding specific countries since learning rates are usually calculated based on the overall levels of deployment (internationally) and learning of a specific device (or grouping of devices) rather than within the context of a specific national boundary, (unless one assumes that all deployment occurs within that country). Therefore, the wider the scale of deployment estimation taken into account, (i.e. wider geographical assessment) the more 'comprehensively' one can argue the deployment experience rate to be.

As a result of these cumulative uncertainties within wave energy cost estimations, it is clear that experience curves do not provide a large level of insight into the knowledge generation being created within this sector, and furthermore, may hinder the overall level of legitimacy given the large variation in estimations.

6.5.3 Bibliometrics

Bibliometric studies provide a clear indicator of knowledge generation. Two approaches have been used to gain bibliometric data for the wave energy sector as outlined in the Methodology chapter; direct searching for relevant papers published within the wider academic community, (using Web of Knowledge, EBSCO's 'GreenFILE' database, and Science Direct) and through asking interviewees directly (in question 1(i)) how many papers their institute had published within the three knowledge categories, (technical/engineering, market/fiscal and environmental/planning) related to wave energy technology.

6.5.3a Bibliometric Findings from Desktop Study

Analysis using bibliometric data is (as with most social science data gathering) something of a trade-off between accuracy and speed in the data gathering process. Specific bibliometric search software (such as is available within the Web of Knowledge) does help to extract more accurate data, however the most thorough method is to use wider search terms and file through the responses. This form of search was done conducted for Web of Knowledge, EBSCO's 'GreenFILE' database, and Science Direct, with citations for 'renewable' topic publications with 'wave' or 'marine' within the title, (using active search lemmatization where possible). The findings were then downloaded, stored, collated and filtered for replication and relevance, leaving a total of 347 publications since 1966, as shown in Figure 56:

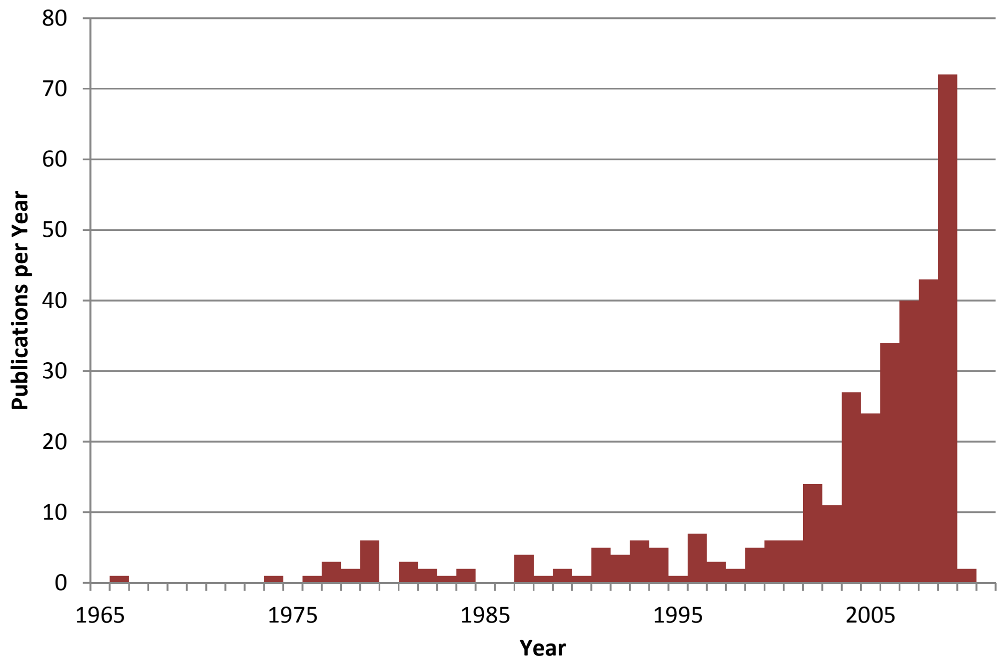


Figure 56: Number of Wave Energy Specific Publications per Annum (Thomson Reuters, 2002, EBSCO Publishing, Elsevier, 1997)

As can be seen, this process suggests a considerable increase in wave energy publications within the last decade. Several reasons exist for why this may be the case, in addition to the fact that there has been an increase in publications within this field, most notably that since the online search engines were started, (most around the start of the century) the back-catalogue of publications loaded into the system has been far less than the number that have been added over the years of operation. Likewise, the culture of publishing has changed dramatically as the number (and scope) of publications in which authors can publish has increased substantially over the last decade.

A further dimension that is not made explicit as a factor to be taken into account within established methodologies for bibliometric studies as an indicator for system functionalities is the 'impact factor' weighting that journals have had. This is a dynamic measure of the amount of impact that a journal has had within a research field, based on the average number of citations each article has received in the two years prior, (i.e. number of overall citations from the last two years divided by the number of citable articles within the publication for the same period (Thomson Reuters, 2011)). Effectively it is a measure of the influence that the journal overall has had and thus a proxy for the influence of the papers within it, (a more in depth assessment could be conducted to do a citation analysis of each individual paper; however this is beyond the resources available for this study).

6.5.3b Bibliometric findings from Interviews

Respondent universities from question 1(i) represented 11 out of the total interviewed (14) which therefore makes up 50% of the total universities working within the UK wave energy sector (22). The total number of publications listed as being relevant to the UK wave energy sector was 306 (236 Technical/Engineering, 29 Market/Fiscal and 41 Environmental/Planning), broken down as shown in Figure 57 below.

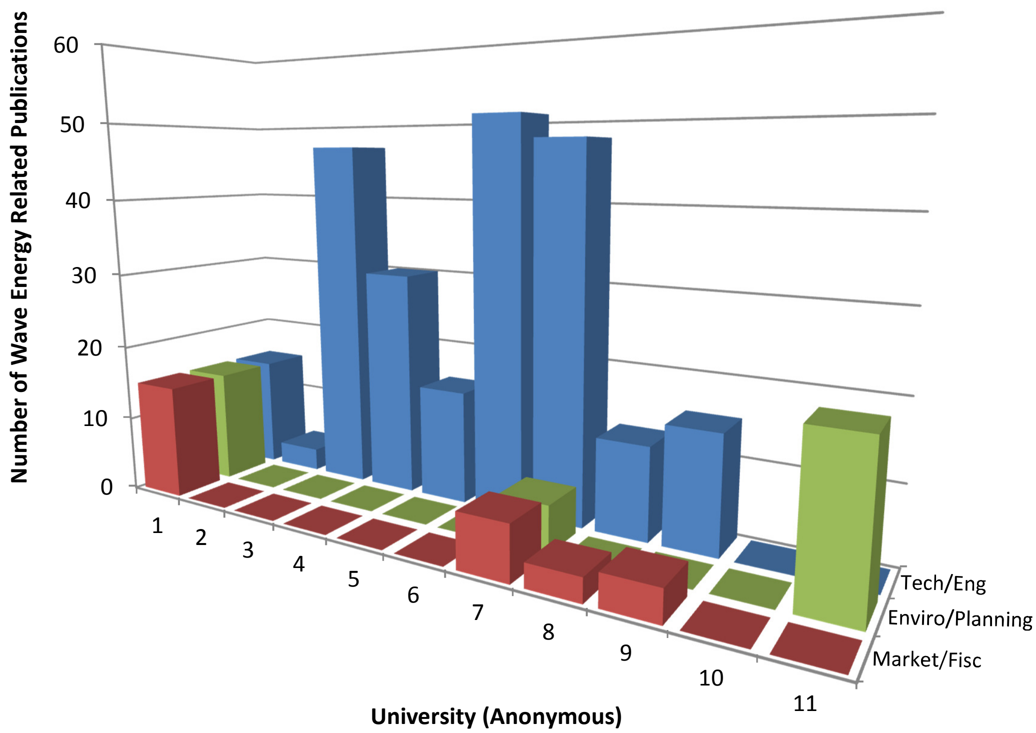


Figure 57: Number of Wave Energy Sector Related Publications Respondent Universities Claimed to Have Published

These figures are clearly lower than those found through the desktop study, however this represents only half or so of the universities thought to be active within the sector. If one were to multiply up the results based on average publications per university or device, a weighting system based on the average number of publications per researcher the figure would almost certainly be well in excess of 450-500 publications. However these figures only represent UK wave energy sector researchers (as opposed to the international search criteria of the desktop study). Several valid explanations for this disparity can be proposed:

- Lack of inclusion of conference papers: Conference and workshop papers make up the bulk of most publications since (in general), they are easier to publish. The interview study did not discriminate between conference and journal papers (therefore increasing the number of publications) whereas the desktop study excluded some (if not all), of the relevant sector conference publications, (such as those at the European Wave and Tidal Energy Conference (EWTEC) and the International Conference for Ocean Energy (ICOE)), as well as the multitude of more subject specific conferences.
- Search engine lack access/subscription: The bibliographic search engine may lack access to all journal papers which were published by those primary system actors who were interviewed. This would therefore result in less publications being found from the desktop study than have been published.
- Lack of search specialisation: Many of the papers that have been published by those who would consider themselves to be working within the wave energy sector (e.g. working on environmental assessments for sub-sea cables) may write articles that are too specific to their topic to be included within the search parameters of the database search.
- Failures within the primary interview stage: Those interviewed may have made erroneous estimations as to the number of publications made relevant to the wave energy sector. This problem of interviewees being unsure as to 'who is doing what' is more prevalent within academic institutes due to the often segregated departmental structures that operate at these institutes.

6.6 Legitimacy

6.6.1 Public Perception of Legitimacy

At the highest level of legitimacy, the public perception of a technology or sector represents the broad and approximate 'feeling' towards a technology and its overall viability. This perception can be thought of as the slow moving but weighty tide of opinion that politicians and the media are both influenced by and have influence upon.

The UK government commissioned an annual survey on renewable energy technology awareness from 2006 until 2009 (the last publication before the survey was stopped) which included a categorisation for wave energy technology within its questions. Additionally, the DTI, in conjunction with the Scottish Executive, DTIN and NAW commissioned a 2003 public perception document on renewables that acted as the initial template for these later studies. All of the 2006-2009 surveys involved between 1870 and 1977 respondents whereas the 2003 survey covered 1279 respondents; all were from a representative demographic of the GB (and NI in the 2003 report) population (TNS, 2003, GfK NOP Social Research, 2006, GfK NOP Social Research, 2007, GfK NOP Social Research, 2008, GfK NOP Social Research, 2009).

Respondents for each survey round were prompted by the questionnaire and respondents asked whether they were aware of the technology. Findings for wave energy technology can be seen in Figure 58 below.

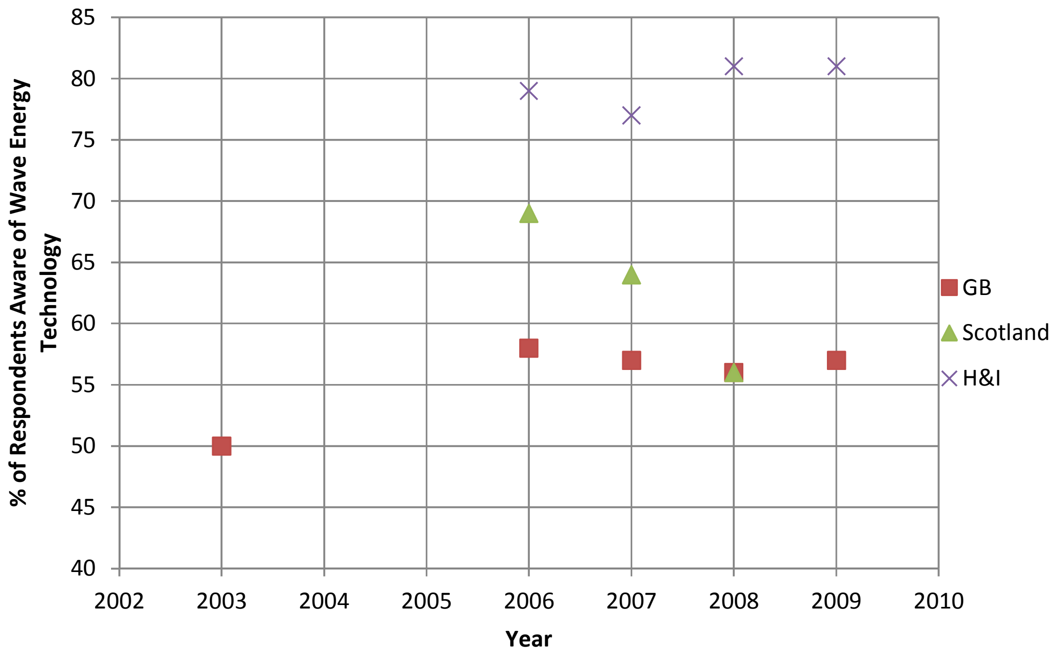


Figure 58: Public Awareness of Wave Energy Technology within the Great Britain (TNS, 2003, GfK NOP Social Research, 2006, GfK NOP Social Research, 2007, GfK NOP Social Research, 2008, GfK NOP Social Research, 2009)[5]

As can be seen, wave energy generally has a high level of recognition, (although out of those surveyed it was below tidal (58%), biomass/bio-energy (59%) and landfill gas (60%) but above geothermal (51%) in 2009 GB) especially within the Highlands and Islands where 81% of the 2009 respondents were aware of it. One very surprising finding is that from 2006 to 2008 responses for different regions, it is clear that Scotland in general, (and despite the very public government push for marine energy) experienced a large fall in recognition of wave energy

[5] Note that the 2003 data includes a representative sample of respondents from Northern Ireland whereas the 2006<2009 surveys were within Great Britain only. Scotland data for 2009 was also missing from the survey.

technology from 69% down to 56%. Figures for Scotland alone were not provided within the 2009 report.

Although individual levels for technology approval were not polled, the survey asked how much they were in favour of renewable energy technology on a scale of 1 to 10, (where 10 was totally in favour and 1 was totally against) as an alternative to fossil fuels such as coal and gas. Respondent's answers are shown in Figure 59 below.

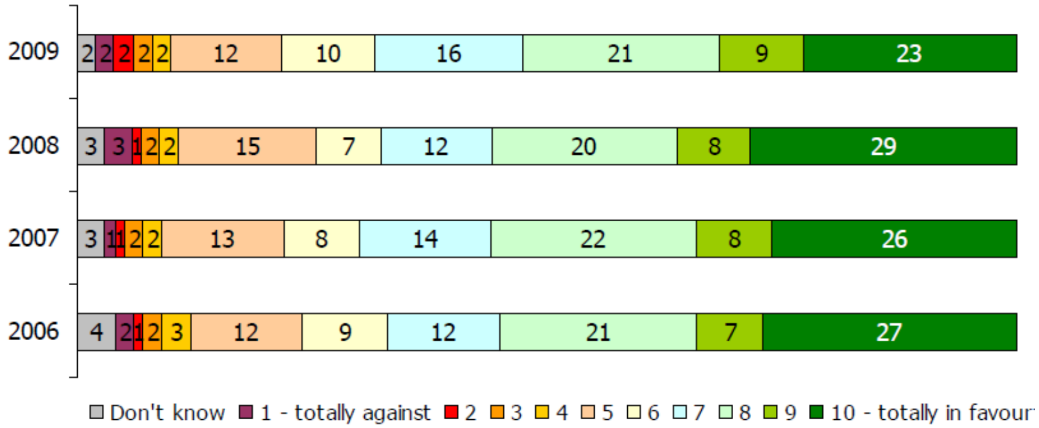


Figure 59: Public Support the use of Renewable Energy as an Alternative to Oil and Gas (GfK NOP Social Research, 2009).

Mean average scores for Highlands and Islands and Great Britain overall (inclusive of H&I) are also shown in Figure 60.

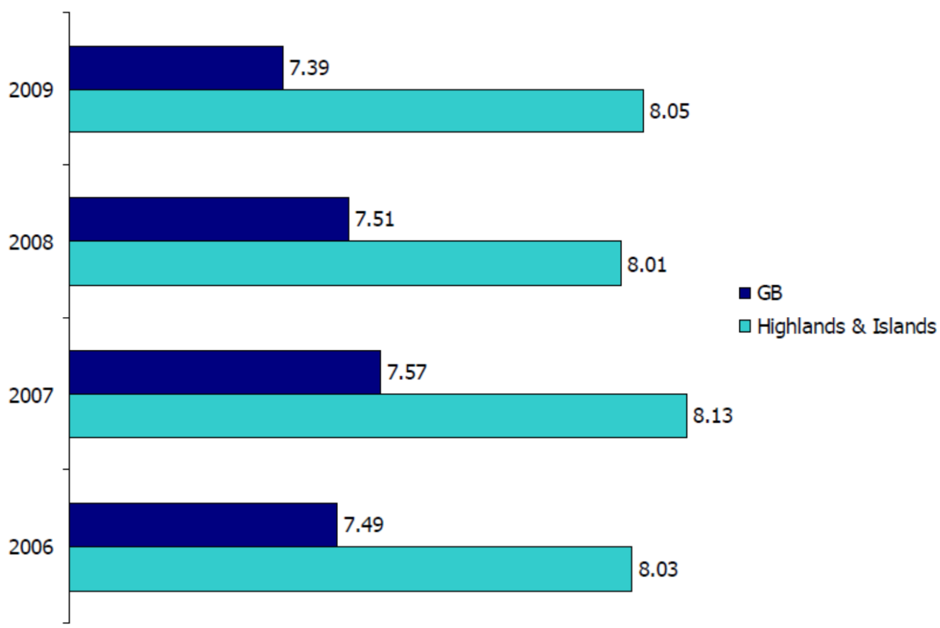


Figure 60: Mean Average Scores of Support Rating for Renewable Energy Technologies as an Alternative to Fossil Fuels Broken Down by Region (GfK NOP Social Research, 2009).

What can immediately be seen from these Figure 60 is that the Highlands and Islands not only have a consistently higher level of recognition for wave energy technology then the GB average, they also have a far higher overall approval rating for renewable energy technology. This is most likely in part due to their longer history of involvement within the onshore wind and hydro power sectors (with 43% of Highland and Island interviewees stating that living near to a renewable energy technology influenced their opinion on renewables) as well as the government promotion that marine renewable energy overall offers the potential to diversify from the declining offshore (oil and gas) industry (see below).

6.6.2 Government Representation of Legitimacy

One of the key indicators of legitimacy for a sector (and indeed legitimising tools for government) is that of government policy statements that both influence and respond to public perceptions of a technology (33% of the 2009 renewable energy awareness and attitudes survey stated that government sources influenced their opinion on renewable energy (GfK NOP Social Research, 2009)). This in turn affects the 'cognitive legitimacy' of the technology, decision makers making within the technology sector and, over time, filters down into regulatory re-alignment regarding the technology (i.e. regulatory legitimacy (Geels, 2004)).

Although oversight of energy generation is not a devolved responsibility of the different national administrations, funding for particular development projects, and economic stimulation initiatives (such as the development of business incubators or local clusters) are within devolved administrative mandates. The three main British government bodies, (the UK Government through DECC, the Scottish Government and the Welsh Assembly Government) have all published policy statements that collectively fulfil this role. Individual government departments (such as Scottish National Heritage), who hold a responsibility within the sector also publish policy statements that are more specific to their remit and (in theory) put the finer resolution of operational detail into wider government agendas.

6.6.2a UK Government

In 2010, DECC published the Marine Energy Action Plan summary report (MEAP)(DECC, 2010b). This document outlined a roadmap for technology roll-out and deployment, a broad sector development strategy for the government's delivery partners (i.e. NDPB's such as the Carbon

Trust and the UK funding councils), a framework for continuation of the (then current) SEA work being conducted, as well as identifying and outlining current constraints for future scale deployment (such as supply chain and regulatory constraints).

In reaction to this, RenewableUK compiled responses from thirty different industry stakeholders, including five of the 'big six' utilities (Centrica have no involvement in the sector) as well as NaREC and EMEC (RenewableUK, 2010b). Although recognised as a significant step for the development of the industry, the MEAP was criticised for several key points and specifically for a lack of fiscal commitment. RenewableUK cite the need for an additional £220M on top of MRPF and MRDF commitments (see Resource Mobilisation) by 2015. They also suggested that in the region of £1billion in total over the next ten years (until 2020) is required to secure a large section of global market share in the marine energy sector. Additionally, they stated that the Department for Business Innovation and Skills (BIS) should produce a strategy for assessing and maximising emerging skills and expertise within parts of the overall supply/value chain.

Effectively, RenewableUK's compiled industry response suggested that although the MEAP is a valuable document, it lacks the fiscal backing behind it that the industry believes is missing from the sector. This finding supports the results for question 8(b) of the primary interviews in which respondents were asked what they perceived as being the largest bottlenecks towards commercialisation of the sector in three different categories, (Market/Fiscal, Technical and Planning & Environmental). Although very qualitative in nature, it can be seen in Figure 61 below[6] that market and finance factors were perceived to be the largest singular bottleneck within the sector, with almost exactly 60% of respondents suggesting this was problematic. This was followed by technical factors which 49% of respondents thought problematic and finally planning and environmental factors which only 28% stated as problematic.

[6] N.B. These do not add up to 100% since those factors that were not mentioned and were not therefore assumed to be 'OK'.

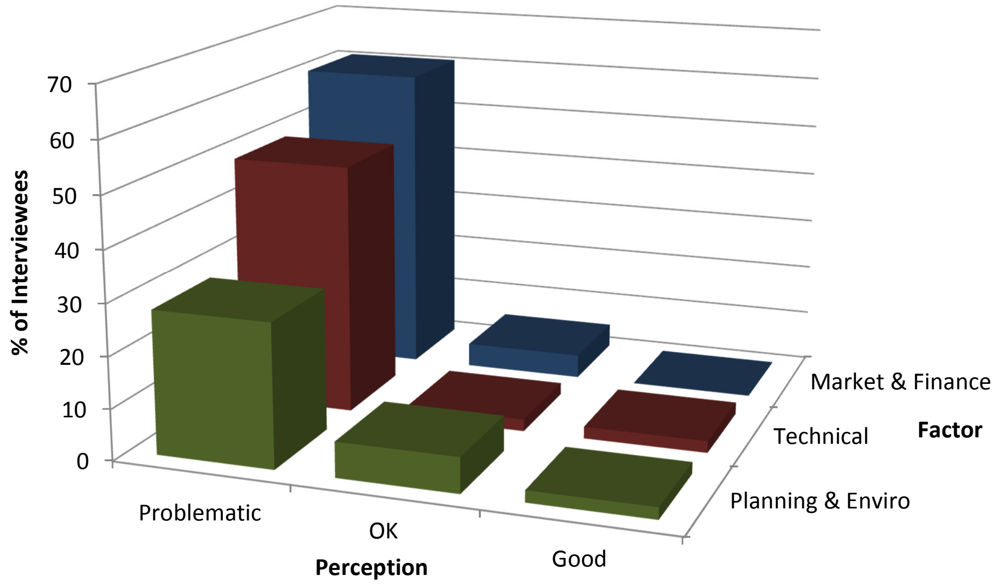


Figure 61: Respondent Perceptions to Potential Bottleneck Factors to Commercialisation within the Wave Energy Sector

6.6.2b Scottish Government

Scotland has for some time displayed a strong political will for wave (and indeed all marine renewable) energy technology, and claims by first minister Alex Salmond regarding Scotland having the potential to be the 'Saudi Arabia' of marine energy have only helped to enforce this image (BBC, 2008) (See Background to the Sector Chapter).

Scotland's marine energy policy statement is somewhat less lustrous in presentations then DECC's MEAP (being only available online through its website (Scottish Government, 2009b)). However it is backed up by a far higher level of both revenue subsidy and Scottish waters grant support programmes (see Resource Mobilisation section (6.2) within this chapter) as well as a fully completed SEA in 2007 (Faber Maunsell and Metoc plc, 2007) not to mention the many other factor condition that are external to Scottish Government control that help to increase the legitimacy of Scotland for technology development and deployment.

The Scottish Government policy statement highlights Scotland's overarching ambition to reach 50% of total electricity demand from renewable energy generation by 2020, of which it believes that 1.3GW of capacity could come from marine renewables (over half of that suggested through the MEAP). It also clarifies the total wave resource around Scottish waters as 14GW, (10% of the EU total resource) and reiterates the Scottish Government's long term commitment to help exploit this resource.

Interviewees were asked in question 8(a); “which do you believe shall be the dominant WEC Country in 2050 (in terms of both manufacturing and deployment), England and Wales or Scotland?” Of those who responded, over 90% of said that they believed Scotland would be the dominant country as can be seen in Figure 62 below.

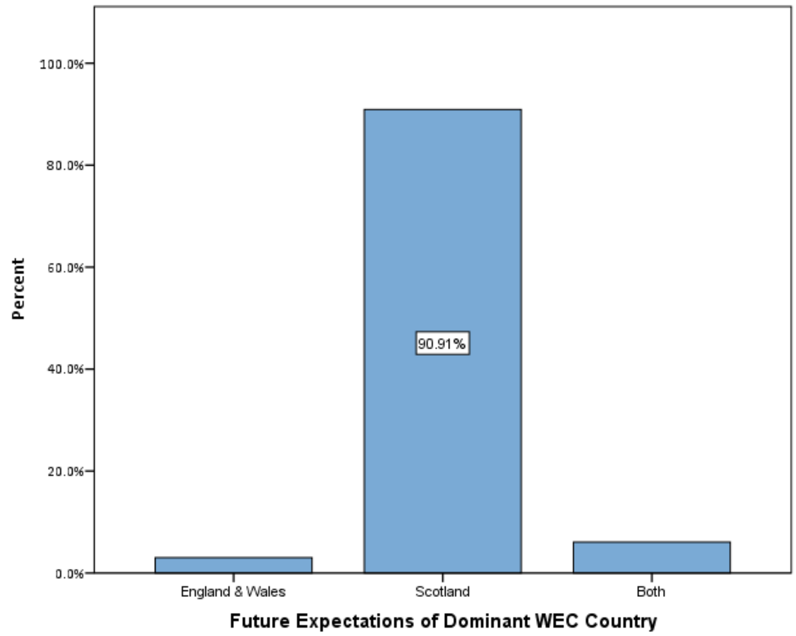


Figure 62: Respondent Expectations as to Which Country will be most Dominant in the Wave Energy Sector by 2050

6.6.2c Welsh Assembly

The Welsh Assembly Government published its overall energy policy statement in 2010 in which it covered its broad ambitions for marine energy (Welsh Assembly Government, 2010). In this document it sets out a target of 10% exploitation for its coastal wave and tidal resource by 2025, (equating to an ambitious 4GW). Although the document does not provide a roadmap for this deployment, it does state in the wave and tidal stream energy section that that they will “promote Wales as a low carbon economic area for tidal energy.” Clearly here they are explicitly omitting wave energy technology from this section. This is not surprising given their strong tidal energy resource and relatively low annual mean wave power (see the Wave Energy section (3.2) of Chapter 3: Background Review of the Sector).

6.6.3 Investor Perception of Legitimacy

Perhaps the most influential stakeholder and therefore purveyor of legitimacy (after central government policy statements) for the sector is that of customers and investors. In the case of wave energy technology these customers are represented by the utility providers. Their policy statements and ambitions regarding wave energy technology play a vital role in informing potential stakeholders whether there is indeed a market emerging (since policy rhetoric is clearly insufficient if not backed up with action to drive technology development and creation of markets).

> "For us, large scale has been a key mantra, and to do it large scale in ocean energy, that means in most cases that you have to go offshore."
>
> Utility Company

The key utility companies, (that are vertically integrated within the power sector, operating as both a generation company as well as a customer supply company) operating within the UK are EOn, British Gas (owned by Centrica), RWE, Scottish and Southern Energy and Scottish Power. Four of these six companies are currently developing wave projects (See Materialisation section (6.4) within this chapter). These four all have marine policy statements online that refer to their commitment to wave energy technology (Scottish and Southern Energy, Scottish Power Renewables, RWE NPower Renewables, EOn).

Additionally, there are four other site development companies currently involved in marine energy projects. These are: Vattenfall Power (wave), International Power (tidal) and two device developer companies that are also embarking on project development: Pelamis Wave Power (wave) and Marine Current Turbines (tidal).

All four utility company stakeholders who responded to question 8(a) in the survey said that they believed Scotland would be the dominant wave energy country within the UK by 2050. Nonetheless, of the five utilities interviewed, four said that wave energy would only play a fractional part within their company's future generation portfolio while only one suggested that it would represent around 5-10% by 2030.

With regards to future technology expectations, there was little consensus among the utility companies, however Table 32 below highlights the technology types being investigated by the developers within the UK.

Technology	Frequency
OWC	1
Semi-Fixed/Fixed	2
Non-Fixed	2
Overtoppers	0

Table 32: Technology Type under Commercialisation within the UK by Utility Companies

Further analysis of the utility investment perspectives is covered within the Market Formation section (6.7.2) of this chapter.

In 2010, communications consultancy Kreab Gavin Anderson was commissioned by DECC to conduct a study into the investor community perspective on the marine energy sector which involved 21 banks, venture capitalists, angel investors and investing corporations. (Walter, 2010, Kreab Gavin Anderson, 2010).

As with the primary interview respondents, investors who were already active within the sector believed that financing and costs were the largest specific issues affecting the marine energy sector as can be seen from Figure 63 below.

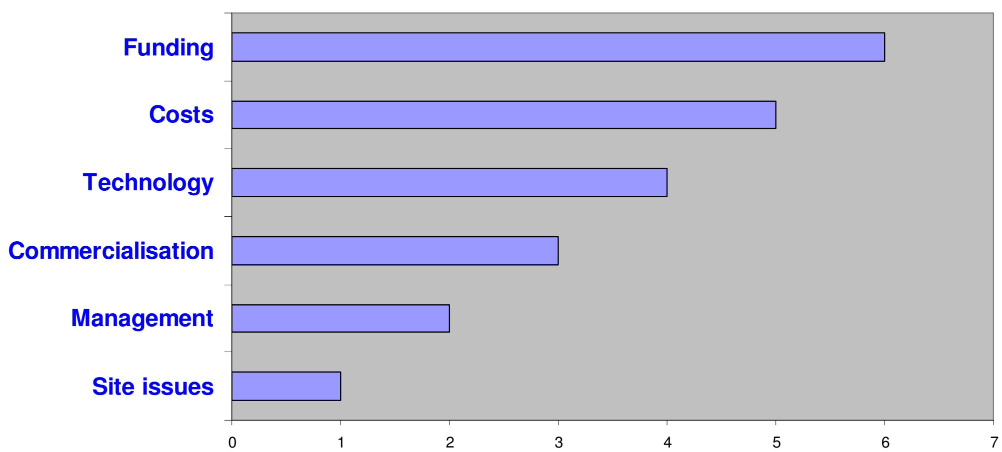


Figure 63: Currently Active Investor's Key Issues with the Marine Energy Sector (Walter, 2010)

Interestingly for potential investors, the technology uncertainties were seen as a larger issue than financing or cost as can be seen from Figure 64 below.

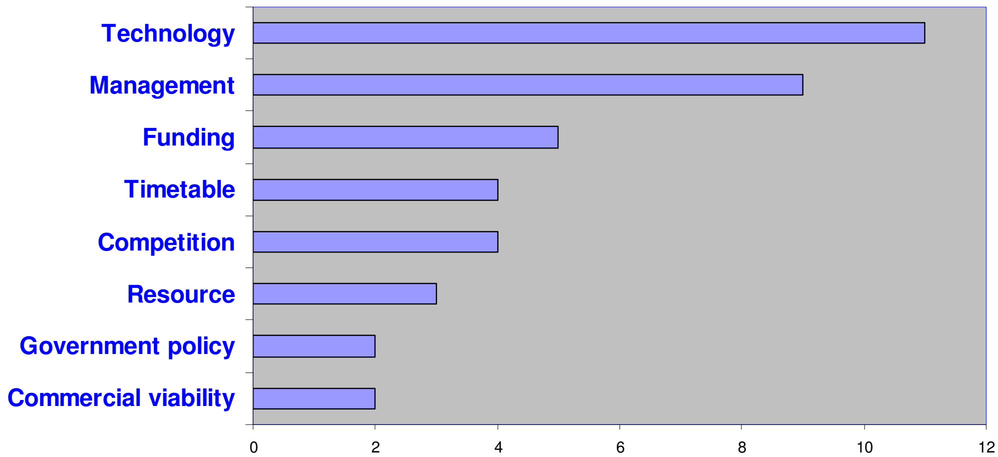


Figure 64: Potential Investor's Key Issues with the Marine Energy Sector (Walter, 2010)

6.6.4 Internal Perceptions of Legitimacy

One of the primary indicators of legitimacy within the wave energy community is simply to assess which technologies are present and at what level of maturity. This is shown in Figure 65 below:

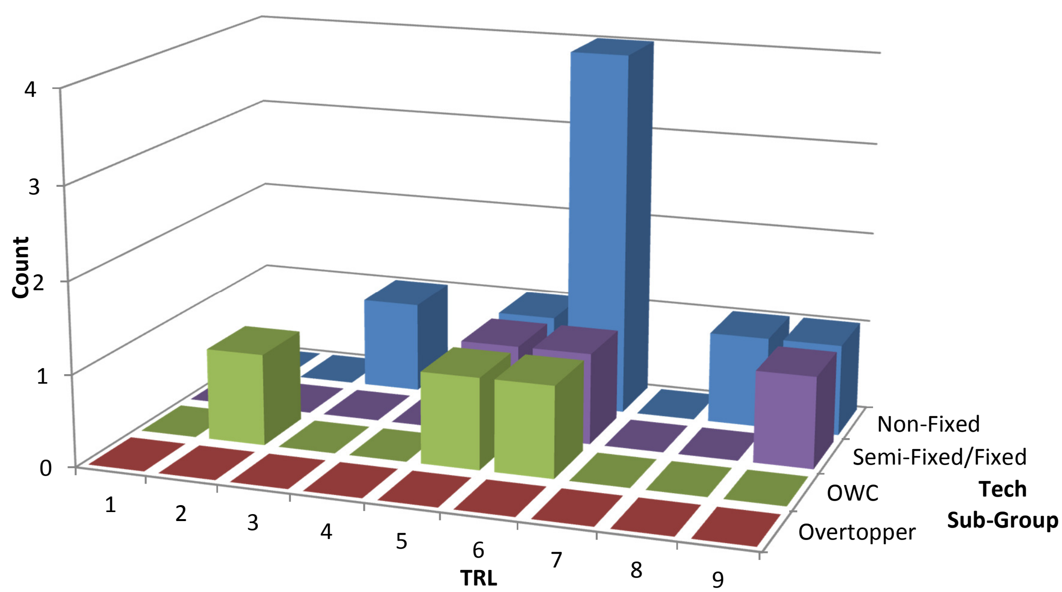


Figure 65: UK Wave Energy Developer Technology Readiness Levels

It is evident that there are a larger number of non-fixed devices being developed within the UK, though notably there are no overtopping style technologies which may have a technological reason, (i.e. the technology is less mature as outlined in Figure 67), geographical reasons, (i.e. the wave climate and bathymetry does not support the technology type) or simply a market reason (no one has decided to investigate the technology). Nonetheless, it is clear that non-fixed devices are far better represented within the UK, (specifically eight device developers against three OWC developers and three semi-fixed). This is interesting as it shows a variation on international patent research distribution as shown in the Knowledge Generation section (6.5.1b) of this chapter.

In question 3(b), all interviewees (except device developers and central government) were asked to rate how commercially viable they believed the different technology sub-groups were from 1 to 10, (1 being not at all promising, ten being almost certain to commercialise). Answers from the twenty eight respondents have been categorized per technology into percentages of performance expectation as can be seen in Table 33 and Figure 66 below.

	Overtoppers	OWC	Semi-Fixed	Non-Fixed
1	7.1	6.7	0.0	0.0
2	21.4	0.0	14.3	0.0
3	35.7	20.0	0.0	6.3
4	7.1	0.0	14.3	0.0
5	14.3	20.0	21.4	12.5
6	0.0	6.7	7.1	0.0
7	7.1	26.7	35.7	43.8
8	7.1	0.0	7.1	18.8
9	0.0	13.3	0.0	18.8
10	0.0	6.7	0.0	0.0

Table 33: Interviewee Perceptions of Technology Sub-Groups

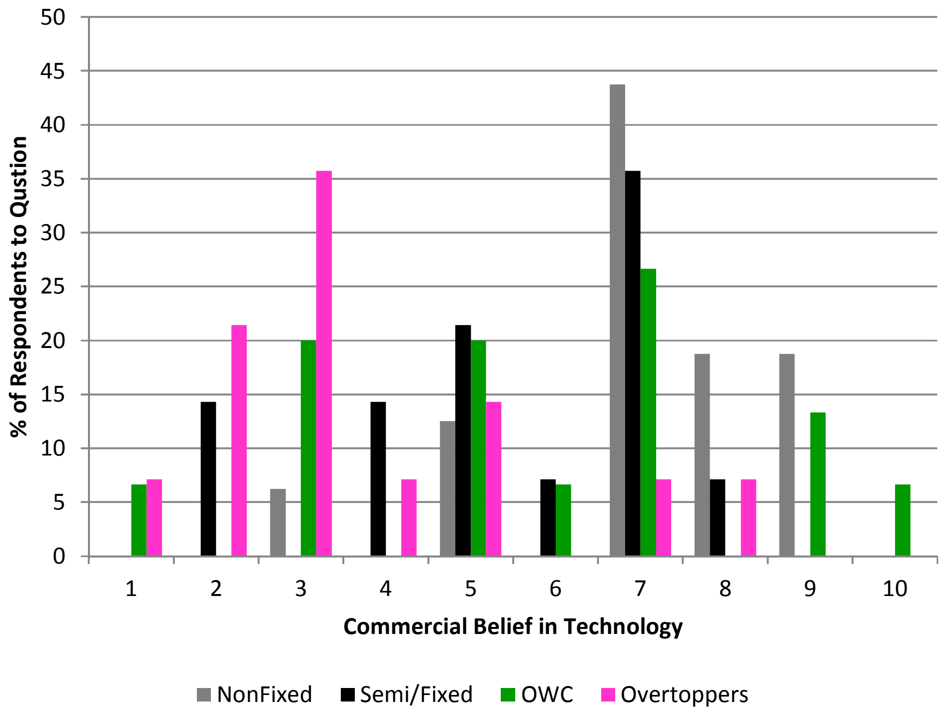


Figure 66: Interviewee Perceptions of Technology Sub-Groups

It can be seen that there is a positive bias towards non-fixed devices, and (to a lesser extent) semi/fixed devices and OWCs. Overtopping devices are clearly thought to be less commercially viable in the long term with almost 65% of respondents scoring its commercial viability at 3 or below. This perception is consistent both with the lack of overtopping device developers currently established within the UK (see Figure 65) and HIS's statement in Figure 67 that states overtopping devices are less commercially developed then others.

> "Purely from the scale of deployment that is required by 2050, then you have to go to non-fixed devices."
>
> University

In answering question 3(b) above, there was a fairly cohesive belief that in the long term, large scale deployment would only be found using non-fixed (floating) devices that could be placed further out to sea and therefore have access to a larger scale of resource. There was however an acknowledgement that the technical challenges of both O&M and installation for such large scale offshore deployments were still very much under-researched and thus the near term costs of deployment would be lower for fixed/semi-fixed devices which, (being deployed at near-shore locations) would be lower. Interestingly, this perception of commercial validity is not consistent with either world or UK patent statistics in which there are far more patents for fixed/semi-fixed devices as can be seen within the Knowledge Generation section (6.5.1) of this chapter.

6.6.5 Legitimacy of the Technology

At a finer level of analytical resolution, the level of legitimacy that applies to different wave energy technologies is very closely aligned to the internal influence upon the direction of search.

> "The marine energy industry and the British Standards Institute should progress the important guidelines and standards work that is currently being undertaken."
>
> (RenewableUK, 2010b)

Clearly, the wave energy sector is one in which there are high levels of heterogeneity among devices and thus, being able to predict which technology (if there is indeed one) the sector is most likely to converge on (and thus commercialise) is something of a 'holy-grail' for both investors, policy makers and device developers themselves.

Current leading technologies have influence upon the perceptions of legitimacy for different technologies, however wider conceptual legitimacies play an important role in what stakeholders and the general public believe is likely to be the most promising technology, regardless of the technical viability at the time. This creates a feedback affect since it influences the direction of search, and, in turn, the overall level of technology development and materialisation. As technologies are further refined and costs bought down, there is a positive re-enforcing cycle of legitimation which may have initially been based upon bounded rationality decisions (such as for example national fore-running technologies or well publicised technology failures).

With regards to technology sub-groups, there has been very little published as to which technology purports to be the most economically viable so far. One of the only examples of this 'ranking' type was made by IHS as can be seen in Figure 67 below.

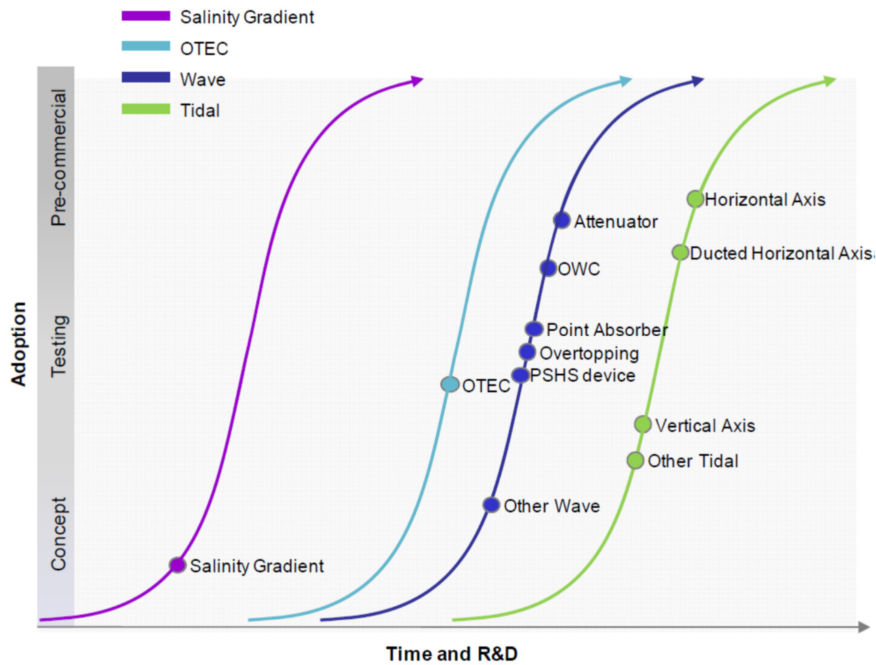


Figure 67: IHS Emerging Energy Diagram (IHS Emerging Energy Research, 2010)

6.7 Market Formation

When assessing the market formation process, the first step is to identify (through the level of materialisation) the market's current phase. The low absolute levels of deployment leave little doubt that the UK wave (and tidal) sector is in a 'nursing' or R&D stage of market formation (Bergek *et al.*, 2008a). There are high levels of uncertainty and risk associated with the sector, no clear dominant design and very little diffusion of the technology both nationally and worldwide.

6.7.1 Formation of Networks

Within the UK (and within a European context) attempts have been made to create various networks (or network projects) both by local/national and international governments for the purposes of assisting with commercialisation of the wave energy sector, whether through R&D support, collaborative institutional lobbying and reform assistance, or for specific site communal planning and development concerns. Additionally, networks are established by industry (such as trade associations) for the purpose of lobbying for their members and ensuring that the interests of these members, (be they skill and employment issues, financing and markets, technical breakthroughs or networking events for example), are bought to the public eye and addressed if needs be. The (UK) networks are listed (in size of members) in Table 34 below (NB. personal representation networks such as IMechE, the Energy Institute and the International Network on Offshore Renewable Energy are excluded from this list although it is acknowledged that these play a role in specific personal development utility.

Network Full Name:	Name	Est.	Value	#	Network Summary:
Aberdeen Renewable Energy Group	AREG7	2001	na	60	Aberdeen City and Shire based incorporated company, working to established the region as a key location for all renewables through targeted support funding, (notably the annual All Energy event)
RenewableUK	Renewable UK	1978	na	52	UK trade body for wind. In 2004 it adopted wave and tidal technologies under its remit. Focussing on lobbying, skills, information dissemination and a general forum for industry discussion and representation
Marine Renewables Industry Association	MRIA	2009	na	23	Irish lobbying body for wave and tidal ocean energy focussing on leasing, grid connectivity, research and public awareness
Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact	EQUIMAR	2008	€5.44m	23	EU-FP7 project focussing on standardisation protocols for site selection, device engineering design, deployment of arrays, environmental impact, and economic issues (now closed)
Renewables Advisory Board	RAB	2001	?	19	QUANGO UK government advisory board (Now abolished) established to make recommendations on a wider range of RE policies, programmes and measures
Subsea UK	Subsea UK	1997	NA	18	UK sub-sea industry body representing over 200 companies interests. Focussing on lobbying, skills and training and assisting its companies

[7] Networks in which only participants referenced as 'wave and tidal' active are included

Network Full Name:	Name	Est.	Value	#	Network Summary:
Forum for Renewable Energy Development in Scotland Marine Energy Sub Group	FREDS MARINE ENERGY GROUP (MEG)	<2004	?	17	Scottish government led RE support network focussing on economic development, skills and practical deployment within the Scotland
Marine Renewable Integrated Application Platform	MARINA PLATFORM	2009	€12.8m	14	EU-FP7 Project focussing on all offshore RET infrastructure R&D, specifically for deep-offshore applications
Marine Renewable Energy Development in Scotland	MREDS	2007	£1.5m	13	ICIT (Heriot-Watt University) established project focussing specifically on marine deployment research challenges and opportunities within Scotland
Components for Ocean Renewable Energy Systems	CORES	2008	€4.52m	13	EU-FP7 Project investigating OWC components for both scale-up manufacturing (for mass production) and offshore application (now closed)
Sustainable Power Generation and Supply Marine	SUPERGEN Marine	2003	£8.05m	10	Broad range marine research group investigating generic marine energy challenges with its current 2nd phase focussing on scaling wave/device relationships
Joule Centre for energy Research & Development	JOULE CENTRE	2005	€12.9m	10	North West England based research centre for all renewable technologies, seeking to promote research between industry and academia
Performance Assessment of Wave and Tidal Array Systems	PerAWaT	2007	£8m	8	ETI programme working across industry and academia to help validate device and array modelling techniques to reduce uncertainty of device performance
ORKNEY Renewable Energy Forum	Orkney Renewable Energy Forum	2000	na	8	Local (Orkney) RE network focussed on supporting deployment, economic development, lobbying and employment through RE within the region
Peninsula Research Institute for Marine Renewable Energy	PRIMaRE	2007	£15m	4	Joint academic 'virtual institute' within the South West supporting the development of Wave Hub through both applied research and business engagement & development

Network Full Name:	Name	Est.	Value	#	Network Summary:
RENEW-NET	RENEW-NET	2009	na	5	Scottish based RE 'knowledge hub' providing technical support and grants for SME RE technology innovation support.
Edinburgh Research Partnership in Engineering and Mathematics	ERPem	2006	£22m	3	Edinburgh specifically focussed engineering partnership between 3 universities with a relatively small marine RE component

Table 34: List of UK (participatory) Wave and Marine Energy Networks, Associations and Collaborative Projects

The below Table 35, Figure 68 and Figure 69 details the make-up of the networks (in terms of their ratio of industry to academia/research and government/public sector), and also outlines the ratio of, participants from primary interviews, (i.e. system actors) as well as those referenced as participants (in question 1(a)) and those who were not referenced at all. It should be noted when analysing these network statistics that some of the networks were (as explained above) for both combined wave and tidal technologies, and therefore have a lower than expected ratio of primary system actors.

		Ratio of UK System Actors:			Profile of Network Members			
Network Name:	#	Non-Ref. Non-System Actors	Ref. Non-System Actors	System Actors	Industry	Academic Research	Public Sector	Other: Networks Charities Test Centres
AREG*	60	73%	18%	8%	82%	7%	3%	8%
RenewableUK	52	58%	29%	13%	94%	0%	2%	4%
MRIA	23	74%	13%	13%	78%	4%	17%	0%
EQUIMARE	23	9%	57%	35%	35%	57%	4%	4%
RAB*	19	58%	11%	32%	74%	5%	11%	11%
Subsea UK*	18	56%	28%	17%	78%	11%	6%	6%
FREDS (MEG)	17	6%	29%	65%	65%	6%	24%	6%
MARINA	14	14%	79%	7%	43%	57%	0%	0%
MREDS	13	15%	54%	31%	31%	15%	15%	38%
CORES	13	54%	31%	15%	31%	69%	0%	0%
SUPERGEN	10	0%	10%	90%	0%	100%	0%	0%
JOULE CENTRE	10	50%	30%	20%	40%	40%	10%	10%
PerAWaT	8	0%	25%	75%	38%	50%	13%	0%
OREF	8	0%	63%	38%	25%	13%	38%	25%
PRIMaRE	4	0%	25%	75%	0%	50%	25%	25%
RENEW-NET*	5	0%	0%	100%	0%	60%	40%	0%
ERPem	3	33%	0%	67%	0%	100%	0%	0%

Table 35: Ratio of System to Non-System Actors and Sector Representation in Wave and Marine Energy Networks, Associations and Collaborative Projects

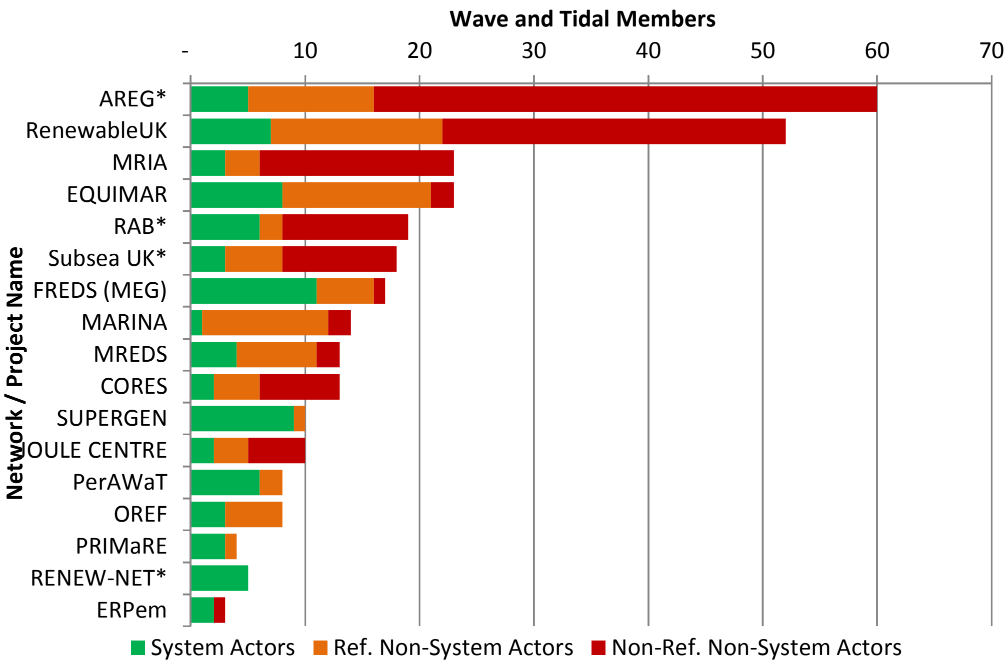


Figure 68: System Actor Representation in Wave and Marine Energy Networks, Associations and Collaborative Projects

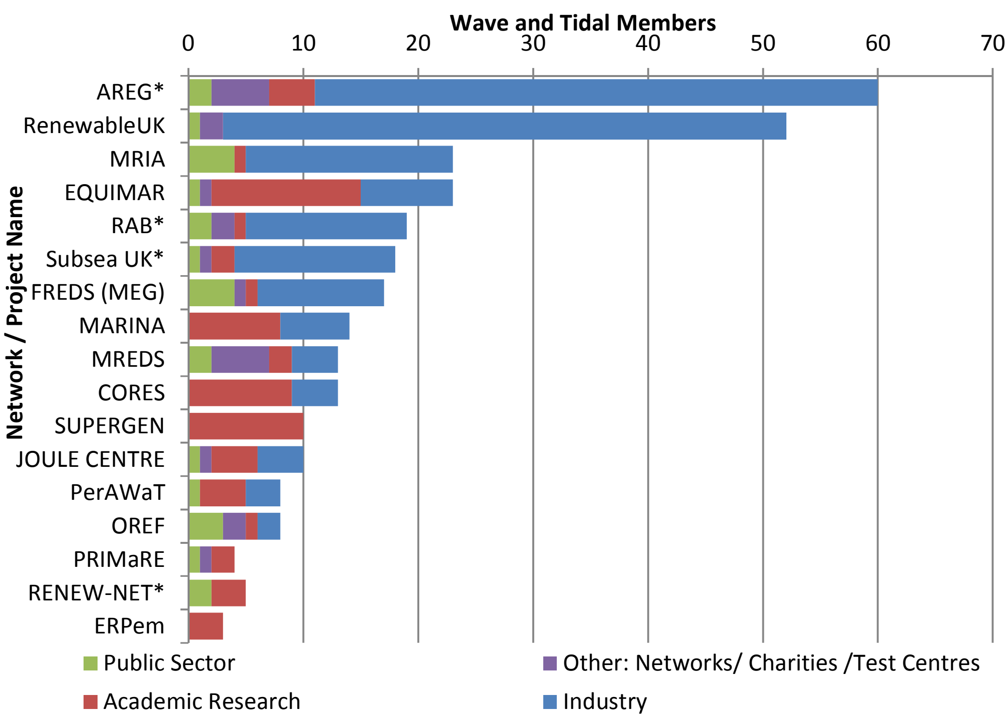


Figure 69: Sector Representation in Wave and Marine Energy Networks, Associations and Collaborative Projects

As can be seen in Figure 69 and the individual networks' description in Table 34, although not wholly distinct, four network sub-categories can be identified as present within the UK Wave/Marine energy sector:

Firstly, large industry representation bodies, (such as RenewableUK, MRIA and SubseaUK) which are heavily representative of (and governed by) industry, focussing on political lobbying at all scales, industry representation and collaboration over common industry problems. These are typically trade associations but not always, as is the case for the now scrapped Renewable Advisory Board (RAB), which was essentially a NDPB established to provide central government policy advice.

Secondly, there are medium/large scale central government led, (whether national or European) mixed academic/industry projects or networks (such as SUPERGEN and MARINA that focus on specific technical problem solving research within the sector. These often have a geographically dispersed nature to them whether national or international, and have a finite time scale and budget.

Thirdly, there are small scale academically led research networks (such as PRIMaRE and ERPem) that are geographical in nature and focus on the joint research interests and lobby ability of a group of universities.

Finally, there are regional economic development networks (such as AREG, MREDS and OREF) that are usually public sector led, (regionally or nationally) and cover the full spectrum of scales depending upon the region but have a specific focus upon assisting the commercial interests, skills, employment and RE deployment (i.e. planning concerns) of the region.

When Figure 69 is re-drawn using these four subcategories outlined above the results can be seen in Figure 70 below:

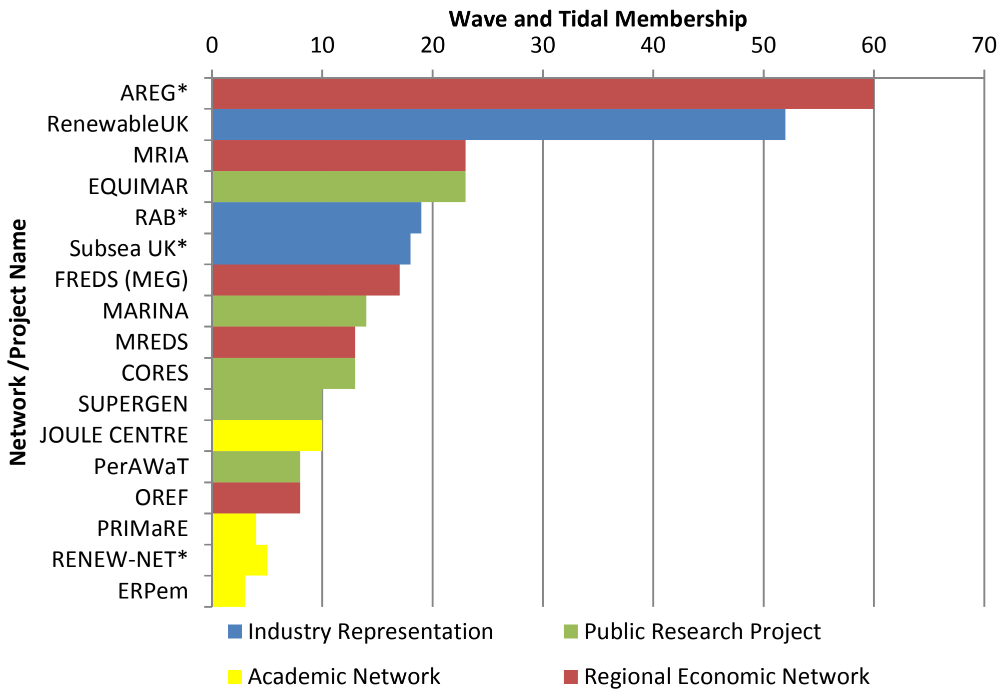


Figure 70: Networks, Associations and Collaborative Projects Sub-Groups

Additionally, these four network types are summarised in Table 36 below:

Network Type	Member Size:	Network Leaders:	Geographical Distribution:	Network Focus:
Industry Rep.	Large	Industry	National	Industrial representation, lobbying and communications
Public Research Project	Medium	Public Sector	Inter-/ National	Sector-wide technical research on bottlenecks. Finite time and funding
Academic Network	Small	Academia	Regional	Joint research and problem solving as well as collective lobbying/tendering ability
Regional Economic Network	Any	Public Sector	Regional	Regional economic development interests

Table 36: Established Network Types Summary

6.7.2 Market Formation Process

In question 7(b), interviewees were asked to name what they believed was required for the sector to be seen as attractive from an investment perspective. Based upon the answers of 38 respondents, responses were categorised into coherent (although in some cases thematically similar) categories as shown in Figure 71 below:

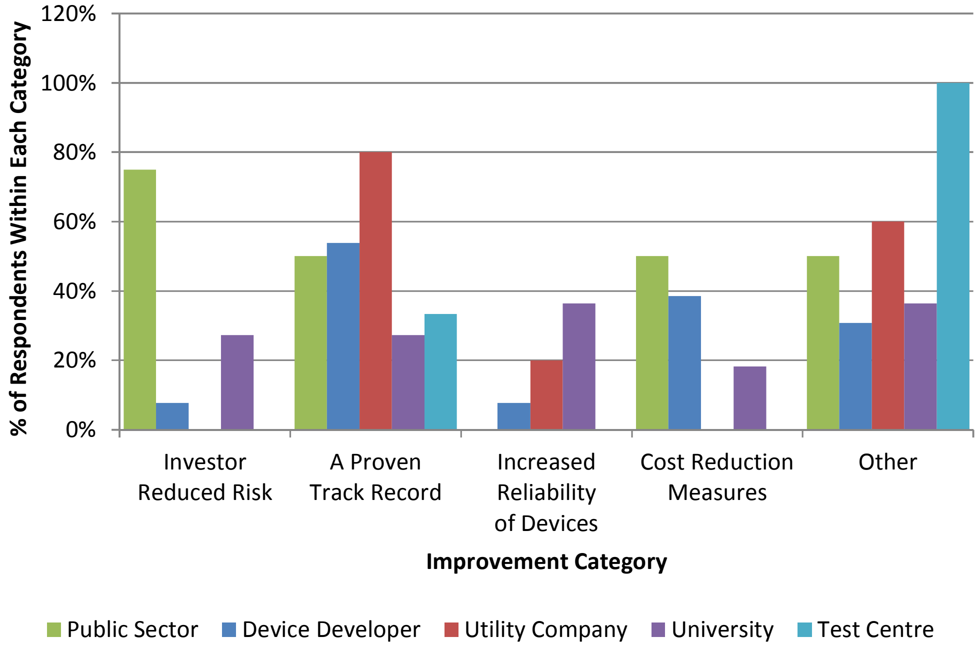


Figure 71: Stakeholder Perception on what is required for the Sector to be seen as Attractive from an Investment Perspective

As can be seen, there is a fairly diverse set of responses, however having a prior track-record of success is seen by 80% of utility companies (the largest private investor category) as being required before investment will be forthcoming.

> "We are inclined to run demonstration projects to see if there is a reliable business within the wave and tidal industry. It's a pragmatic approach but we need a few success stories before putting a wave or tidal project within the strategic planning of the company."
>
> Utility Company

This finding supports qualitative discussions with utility companies who unanimously believed that the wave energy sector is currently a non-commercially viable 'R&D' branch within their operations. When asked (in question 7(c)) what they believed was the medium and long term potential for wave energy technology within the company, all five (utility company) respondents said that it would be a small (but present) component and did not see large-scale commercialisation of the technology in the foreseeable future (unless projects could be assessed commercially against their existing investment project portfolio and provide an attractive NPV return). Clearly, the fiscal attractiveness of these alternative investment opportunities is a large enough externality that they have a significant deciding factor on private sector development and investment.

Question 7(a) asked device developers where they acquired their knowledge of customer expectations (with regards to their technologies performance expectations) prior to having any previous diffusion and thus user feedback. This question sought to draw out whether the demand profile had been clearly articulated to developers. Of the 13 respondents to this question 10 (77%), said that they had direct and continuous contact with utility companies and investors, 1 (7.7%) responded that information was gained through trade associations, and 2 (15%) said that they either did not seek/receive customer dialogue on expectations or they carried out simple desktop studies. This finding shows that there is generally a fairly high level of developer/customer communication present. Interestingly however, there was no strong correlation with these device developers' level of technology maturity and their response to this question.

One of the consistent comments from less technically mature device developers was that they had a hard time communicating with specific funding government bodies such as DECC etc. When asked about this issue, DECC responded that there was high levels of communication with developers, however the natural technology progression through differing government departments, (see Resource Mobilisation section (6.2) within this chapter) was not always being observed and thus there was an internal (to government) system of referring relevant developers to their most appropriate department, (e.g. very early stage technology developers would be referred to the EPSRC).

6.8 Development of Positive Externalities

As discussed in the methodology, codifiable indicators for the development of positive externalities (or 'free utility') are hard to identify since the nature of the specific function is itself not independent, but works through the strengthening (or feedback) of the other functions (Bergek *et al.*, 2008a). Additionally, the notion of free utility relates not only to the internal dynamics of one particular system, (where certain functions may bestow free utility upon others) but also refers to the free utility provided to and from related but separate industries (systems)(Bergek *et al.*, 2008b).

In this respect there have been many instances of positive externality in which the sector has been both benefactor and played a role in assisting the development with other TISs, however these examples are clearly narrative in nature and as such shall be presented in this way in the below section.

6.8.1 Functionality Relations across Sectors

It is clear that 'sibling' systems of knowledge exist or what Porter describes as 'related industries' (Porter, 1990) in which there are commonalities of knowledge, technology, labour pools, working environment and, (potentially) political lobbying interest. These systems are not simply complementary but are also in some ways competing for resources and outcomes (such as deployment targets and in some instances physical space). Offshore wind is clearly a specific example of an 'older' sibling system (since it is a more mature technology and market) whereas tidal can be thought of as something of a 'twin' system due to it's collectively managed technology development within public policy. Figure 72, below, presents a stylised systemic 'family tree' for the wave energy sector.

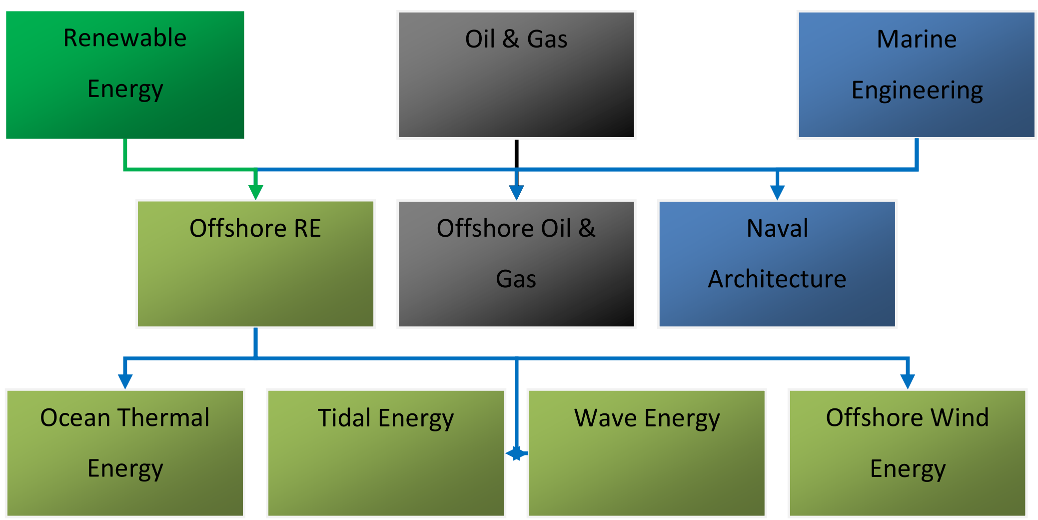


Figure 72: Stylised Systemic Family Tree of the Offshore RE Sector

Many of the commonalities shared between systems can be said to occur within and across functions through the above systems (although it is acknowledged that innovation and resource shifts in less related systems have varying impacts). As such, this section will be broken down into the three most relevant related systems; tidal technology, offshore wind and oil and gas, (those that have been most the highest contributors towards the wave energy sector). Ocean thermal energy conversion and salinity gradient will not be explored as these are far less developed as sectors than even wave and tidal, therefore their impact upon the sector and provision to supply free utility has been considered to be minimal.

6.8.1a Tidal Technology

The tidal energy sector is extremely closely related to the wave energy sector, despite concept designs and power extraction mechanisms being very different. The industries are at similar stages of maturity and have in common many deployment, grid connection and environmental/technical challenges. It can therefore be suggested that there is a high level of complementary knowledge spill over between the two sectors, specifically in terms of environmental monitoring requirements (see for example the Pentland Firth Developers Forum) technical standardisations, definitions and testing (e.g. Equimar, TC114 and the complementary test centres EMEC and NAREC) as well as market knowledge diffusion, (e.g. DECC's Marine Energy Action 2010 document, the ETI Marine Energy Roadmap etc. (Energy Technologies Institute, 2010, DECC, 2010b).

From a socially regulative, normative and cogitative perspective of legitimacy (Geels, 2004), wave and tidal technologies are perceived by many as the 'same thing', since supporting institutional mechanisms and policies, moral benchmarks and public documentation regarding these technologies are very much seen as complementary to both[8]. For these reasons the tidal sector can be seen as extremely complementary to the wave energy sector, with the two technology groups intertwined in their presentation of legitimacy (unlike for example ocean thermal energy conversion technology which is at a much earlier stage of sector/technology development and thus cognitively perceived as a different technology group).

Since many of the skills and knowledge based services required for the wave energy sector (e.g. deployment techniques, offshore cabling, environmental assessment and monitoring) are provided by specialist actors (universities or companies), it follows that there is a likewise complementary coupling of the market formation processes between the two sectors.

Likewise, due to the clear perception of sectoral proximity between wave and tidal, support lobbying, (through bodies such as EU-OEA, OES-IA and RenewableUK) is done almost entirely in a collectivised fashion. This has resulted in joint resource mobilisation of funding and assets such as EMEC and the Pentland Firth leasing rounds, the PerAWat and SUPERGEN research collaborations to name a few.

[8] This is so much so that during the analysis of the wave energy sector within this thesis, the scope of research objectives and data gathering has had to broaden at times to include tidal technology so as to obtain valid and insightful information. (See for example deployment targets within the 'influence upon the direction of search' or the public perceptions of marine renewables within the 'legitimacy' sections of this chapter).

6.8.1b Offshore Wind

Like much tidal technology research, the offshore wind energy sector has many of the same overlapping knowledge bases, specifically in the fields of environmental assessment and monitoring techniques, offshore grid connection and cabling as well as general marine environment engineering. Since this sector is however more developed, much of the collective offshore renewables' sector public and institutional legitimacy has been forged by offshore wind and the UK Government's desire for large scale future deployment. Specifically, this relates to the 25GW of leased capacity licenses announced under the offshore wind round 3 programme (Crown Estate, 2011).

The beneficial spill over changes resulting from this central government energy policy have not only provided future free utilities (such as the planning for a potential offshore 'super grid' and the focus of marine renewables within institutional changes such as the Marine and Coastal Access Act (UK Government, 2009b, Airtricity, 2007)), but has also resulted in an increased awareness and legitimacy for offshore renewables collectively such that wave and tidal has in many ways been bought much more firmly into the public consciousness (with for example the British Wind Energy Agency (BWEA) changing its name to RenewableUK to reflect its new status as a representative body for wave and tidal technologies (RenewableUK, 2009)).

The wave-wind inter-industry relationship is not 'win-win' however, since the offshore wind energy sector currently shares many of the deployment strategies and technologies such as jack-up barges and cabling ships required for future deployment. Additionally, the UK government's required targets for renewable energy deployment capacity are irrespective of the type of technology chosen and so there is in some sense a clear 'competition' to meet this deployment target. To illustrate this point, if (hypothetically) there was a radical and cost cutting innovation to occur around floating wind turbine technology which presented the technology as economically favourable to wave and tidal technology, there is a high likelihood that this would result in an increased deployment drive for floating wind turbines and a subsequent reducing of deployment expectations for wave and tidal technologies, therefore having a detrimental effect upon the wave energy sector.

6.8.1c Oil and Gas

Many of the individual design and construction engineers as well as business managers within the UK wave energy sector initially trained or worked within the oil and gas sector, and one of the strong political factors for the support of marine renewable energy, (especially within Scotland) is the fact that it is seen as a potential migration industry for skilled jobs currently within the oil and gas sector as North Sea reserves decline (Esteban *et al.*, 2011, Scottish Government, 2010b, Allan *et al.*, 2010, Future Energy Solutions, 2002).

As a result of this historic transference of skills, oil and gas is perceived by many as one of the main contributing knowledge bases for the wave energy sector (and indeed all marine renewable energy). Much of the foundation knowledge regarding marine renewable engineering (specifically sub-sea, sea-bed and marine power engineering) originates from the oil and gas sector and so it is no surprise that some of the most developed intense marine renewable activity occurs in places where there is a large oil and gas industry presence. Aberdeen is a notable example, it hosts the annual All Energy event, is home to the Aberdeen Renewable Energy Group and several key marine renewable stakeholders including Robert Gordon University, the University of Aberdeen, Green Ocean Energy and the environmental consultancy firm Xodus Aurora, among others.

Oil and gas clearly have an influence upon the level of entrants into the marine renewable sector (it was the oil crisis in the early 1970's that first stimulated the UK government into researching marine renewable energy in a hope to lower the UK economic dependence upon oil and gas use and thus increase our national energy security (see Early History of the UK Wave Energy Sector section (3.3.1) within the Background Review of the Sector, Chapter). In this respect it is impossible to assess whether oil and gas has had a positive or negative long term influence upon the wave energy sector as, in many ways it was initially the primary catalyst for wave energy research. When prices were low, as they were in the 1980s, research funding within the sector dried up. The relationship between the cost of oil and the amount of marine research funding is mapped in Figure 73 below, and whilst these factors are not wholly correlated it is shown that oil price fluctuations have been followed by ocean energy research spend.

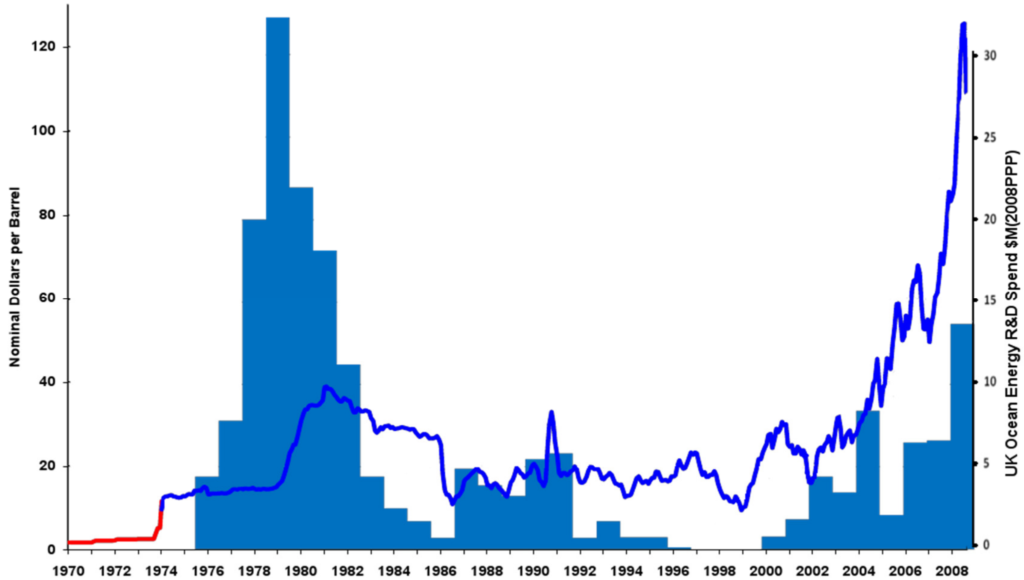


Figure 73: Oil Price Comparator against Ocean Energy Research (IEA, 2010, Energy Saving Trust, 2008)

From a legitimating stance, the oil and gas industry has lobbied against renewable energy historically around the world and certainly within the UK, openly voicing scepticism regarding both the ability of renewable energy to provide for the UK's overall energy transition and the specific availability and capacity factors of individual projects and technologies (Oil and Gas UK, 2010, Webb, 2010).

The three industries, (oil and gas, offshore wind and tidal) have had spillover effects (both positive and negative) upon all of the functionalities of the wave energy sector. A summation of this relationship is shown in Table 37 below.

	Tidal	Offshore Wind	Offshore Oil & Gas
Knowledge Generation and Diffusion	Combined environmental & grid research, test centres & events (not universities)	Combined environmental and grid research	Overall 'spillover' of offshore engineering knowledge
Legitimacy	Strongly assists due to combined perceptions of technology viability	Assists with increasing legitimacy of offshore renewable technology	Lobbies in the interest of oil and gas to the detriment of renewable energy
Market Formation	Assists with complimentary services (e.g. environmental planning etc.)	Assists with complimentary services (e.g. environmental planning etc.)	Neutral
Resource Mobilisation	Assists with leveraging public funding (due to perceptually linked in support)	Competes' for complimentary services (e.g. jack-up barges etc.), skills and knowledge	Varies as 'competes' for complimentary resources however is providing labour pool from waning industry (North Sea)
Entrepreneurial Experimentation	Neutral	Neutral	Neutral
Materialisation	Neutral	Neutral	Neutral
Influence Upon the Direction of Search	Neutral	'Competes' for deployment targets	Varies depending upon oil price

Table 37: Summation of functional affects of related industry upon the wave energy sector

6.8.2 Established Key Indicators

6.8.2a Intermediate Goods and Services

The emergence of intermediate goods within the value chain is seen as an indicative sign that the sector is producing things that can be and are taken from complimentary industries due to their intermediate (i.e. not only functional to the wave energy sector) capability (Bergek et al., 2008b). Currently there is very little in the way of intermediate goods 'common' services or components specifically tailored for the sector such that all device developers can access and benefit from) available to the sector, mainly because there is such low deployment and thus opportunities for such innovation within the supply chain have not yet presented themselves. One technology cost reduction measure that the Carbon Trust have run, called the Marine Energy Accelerator programme, focussed specifically on the cost reduction of 'communal' wave energy technologies, specifically mooring and anchoring systems, hydraulic motors, piping and linear generator technology (Carbon Trust, 2008). This work followed on from the CT's Future Marine Energy document which stated that a step change in the cost of wave technology would be required for wave energy to become commercially competitive (the assumptions at the time were that this would be less than 6p/kWh which equated to the expectations for a 2020 'low fossil fuel' price plus revenue supportable subsidy) within 400MW of deployment (Carbon Trust, 2006), a figure that now, given more recent estimates, ((Committee on Climate Change, 2011, The Offshore Valuation Group, 2010) seems erroneously optimistic. More recently still work has been done through the ETI to design and build a 'low cost' 11kVA wet-mate connector which could be used in a high variety of applications (Energy Technologies Institute, 2012).

6.8.2b Politically Supportive Power

In the main, politically supportive social capital, (in terms of political lobbying leverage for the sector or high profile political support) has come through the Scottish Government which for some time has clearly had a strong agenda to support marine renewable energy within its manifesto, and has provided, among other things, a higher level of subsidy for wave and tidal energy technologies than the UK government until only recently (see Legitimacy section (6.6.2b) of this chapter). Additionally, as mentioned above, the wind representative trade association (RenewableUK) have become strong political advocates of the marine renewable energy sector, hosting, the annual Wave and Tidal event in conjunction with the Crown Estate (who have also been key political advocates for marine energy commercialisation). Other representative networks have also emerged which have less, but still a cumulative impact in the political arena (see Market Formation section (6.7.1) of the chapter).

6.8.2c Emergence of Pooled Labour Markets

The emergence of a sizable pooled labour market is very hard to identify due to the immaturity to the sector. Direct FTE employment and graduate numbers are given in the Resource Mobilisation section (6.2.2a) of this chapter, however there are few if any specific courses available for marine renewable energy developers. Exceptions to this include Heriot-Watt's MSc in Marine Renewables and Strathclyde and Cranfield Universities' separate Offshore Renewable Energy MScs (this does of course exclude the many non-specific BSc, MSc and PhD programmes that cover or allow students to research marine renewable energy).

6.9 Entrepreneurial Experimentation

Entrepreneurs are essential for a well functioning innovation system and without them the sector would stagnate as commercial innovation through experimentation would fail to occur (Hekkert *et al.*, 2007, Bergek *et al.*, 2008a). The UK wave energy sector has been developing since the mid 1970s, (see Early History of the UK Wave Energy Sector section (3.3.1) within the Background Review of the Sector, Chapter 3). Although it was initially heavily led by public sector R&D (as some would still argue it is today) it has always been marked by a perceived high level of market entrants and exits from competing entrepreneurs and their relevant technologies; notable examples include the Bristol Cylinder, SEA Clam, PS Frog, McCabe Wave Pump and more recently the Orecon MRC. Many of these 'failed' devices however, have simply been placed on hold until further funding becomes available, having gone through several desktop (and in some cases deployment) design iterations improvements (such as the PS Frog, now in its Mk5 stage).

This perception of a high turnover of device companies and concepts also masks the fact that over the last decade there has been a large (and currently sustained) level of entrants into the sector as can be seen from the responses to question 5(a) shown in Figure 74 below.

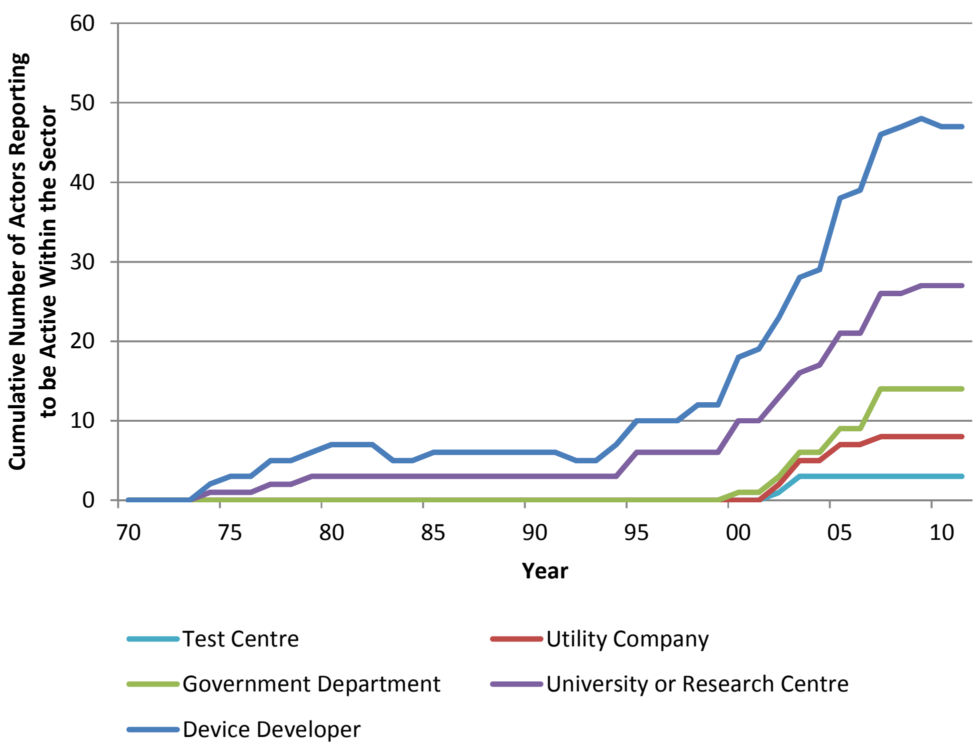


Figure 74: Timeline of Actors to the Wave Energy Sector

6.9.1 Test Centres

What is unique within the UK (in regards to the sector) is that there are now 3 different test centres operating at different scales of device development. Although there are many differences in the sector's current structuring, one of the noted factors that assisted with the commercialisation of the Danish wind industry sector was the established knowledge base presence of the Risø Research Centre Wind Test Station that helped to increase customer confidence and thus legitimate the sector (Karnøe, 1990). The three test centres within the UK (Narec, EMEC and Wave Hub) will cumulatively carry out a similar function and assist in the commercialisation of the sector, with Narec as the first site for device developers conducting scale prototype testing, EMEC carrying out full scale sea tests of singular devices and Wave Hub enabling small arrays to deploy for a monitored period of years if needed. Currently, Narec has assisted with at least 7 WEC device tests (narec, 2008), while EMEC has conducted sea trials with 3 device developers (including both revisions of the Pelamis system) with a further three planning to deploy over the next year (EMEC, 2011) while Wave Hub (only commissioned in November 2010) still awaits its first customer[9].

6.9.2 Entrepreneurial Experimenters (Device Developers)

Based on extensive desktop studies, a total of 111 different wave energy companies have been identified and are listed in Table 38 and broken down by country in Figure 75 below[10].

Company	WEC Device	Website
Australia		
BioPower Systems Pty	bioWAVE	www.biopowersystems.com
Carnegie Wave Energy Limited	CETO Wave Farm	www.ceto.com.au
Oceanlinx	Oceanlinx	www.oceanlinx.com
AquaGen	SurgeDrive	http://www.aquagen.com.au/
Canada		
College of the North Atlantic	Wave Powered Pump	www.cna.nl.ca/OAR/research.asp#WPP
Finavera Renewables	AquaBuOY	www.finavera.com
SurfPower	SurfPower Pontoons	www.surfpower.ca
SyncWave Systems Inc	SyncWave Power	www.syncwavesystems.com

[9] As of time of writing (9th January 2012)

[10] It should be noted that this list shows independent developers who are currently attempting to commercialise there technology. Those that are clearly not currently seeking commercialisation (such as the Edinburgh Duck for example) have been left off.

	Resonator	
Wave Energy technologies	WET EnGen	www.waveenergytech.com
Denmark		
DEXA Wave Energy Ltd	The DEXA converter	www.dexawave.com
Floating Power Plant A/S	Poseidon	www.floatingpowerplant.com
LEANCON Wave Energy	Multi Absorbing Wave Energy Converter (MAWEC)	www.leancon.com
SeaWave Ltd	Tunnelled wave energy converter (TWEC)	www.sewave.fo
Wave Dragon	Wave Dragon	www.wavedragon.net
Wave Star Energy	Wave Star	http://www.wavestarenergy.com/
Waveenergyfyn	The Crestwing	http://www.waveenergyfyn.dk/
WavePlane	WavePlane	http://www.waveplane.com/
WavePiston	WavePiston	http://www.wavepiston.dk
WaveSpinner	WaveSpinner	www.wavespinner.dk
Finland		
AW-Energy	WaveRoller	www.aw-energy.com
Wello Oy	Wello Wave Energy Converter	http://wello.eu
France		
SEAREV	Laboratoire de mécanique des fluides	http://www.ec-nantes.fr/version-francaise/pratique/contacts/m-clement-alain-2738.kjsp?RH=1253611162329
TRIPODELEC	TRIPOD FLOATING ROTULATION POWER STATIONS	http://tripodelec3.voila.net/index.html
Germany		
Brandl Motor	Brandl Generator	www.brandlmotor.de
Greece		
DAEDALUS Informatics Ltd	Wave Energy Conversion Activator	www.daedalus.gr
Hong Kong		
Motorwave	The Motorwave	www.motorwavegroup.com
India		
Power India Technology	Power India Technology Pruthvi	http://www.powerindiatechnology.com/
Agarwal Innovative Engineering Private Limited	Movable Water Turbine	http://www.ainnovative-engg.com/index.html
None (Indian wave energy)	Indian wave energy device (iwave)	http://waveenergy.nualgi.com/
Ireland		
JOSPA Ltd	The Irish Tube Compressor	http://www.jospa.ie/
OceanEnergy	OE Buoy	www.oceanenergy.ie
Wavebob Ltd	Wavebob	www.wavebob.com
Israel		
Nautilus	Nautilus Prototype	http://nautiluswaveenergy.com/
SeaNergy	T.O.P- Turbo Outburst Power	http://www.seanergy.co.il/
S.D.E.	SDE	www.sde.co.i
Italy		
40South Energy Srl	Series 50/100	http://www.40southenergy.com
Japan		
HYPER DRIVE Corporation	Ocean Wave-Powered Generator	http://www.hyperdrive-web.com/P1ENindex.html
JAMSTEC	Mighty Whale	www.jamstec.go.jp
Mauritius		
PES	Balkee Tide and Wave Electricity Generator	http://peswiki.com/index.php/Directory:Balkee_Tide_and_Wave_Electricity

		_Generator
New Zealans		
WET-NZ	WET-NZ Device	www.wavenergy.co.nz
Norway		
ABB & Fred Olsen	FO3	http://www.seewec.org/
Euro Wave Energy	Floating absorber	www.eurowaveenergy.com/ewe/public/openIndex?ARTICLE_ID=100
Ing Arvid Nesheim (IAN)	The Oscillating Device	http://www.anwsite.com
Langlee Wave Power	The Langlee E2	www.langlee.no/
Norwave AS	"Wave Collector"	www.http://norwave.net
Ocean Wave and Wind Energy	The Rig	www. owwe.net
Pelagic Power AS	Pelagic Power 1 (and PP2)	www.pelagicpower.com
Straumekraft	Straumekraft Floating Buoys	www.straumekraft.no
Wave Energy	SSG-concept (Sea-wave Slot-cone Generator)	http://www.waveenergy.no/
EU		
The SEEWEC consortium	SEEWEC	www.seewec.org
Portugal		
Martifer Renewables	ONDA 1	http://www.martifer.com/renewables/
Russia		
Applied Technologies Company	Float Wave Electric Power Station (FWEPS)	www.atecom.ru
Vortex Oscillation Technology Ltd	Vortex-oscillatory power station	www.vortexosc.com
Spain		
Hidroflot s.l	Hidroflot	www.hidroflot.com
PIPO Systems	APC-PISYS	http://www.piposystems.com
Oceantec Energías Marinas, S.L.	OCEANTEC Wave Energy Converter	none
Sweden		
Interproject Service AB	IPS OWEC (Offshore Wave Energy Converter) Buoy	www.ips-ab.com
Seabased AB	Seabased's wave energy converter	www.seabased.com
Seapower Group	FWPV (Floating Wave Power Vessel)	http://www.seapowerinternational.se
Vigor Wave Energy AB	Vigor Wave Energy Converter	http://www.vigorwaveenergy.com/
Wave Power Project Lysekil	Not Listed	http://www.el.angstrom.uu.se/forskningsprojekt/WavePower/Lysekilsprojektet_E.html
The Netherlands		
Ecofys	Eric Rossen's Wave Rotor	http://www.ecofys.nl/
UK		
Aquamarine Power	Oyster 2	http://www.aquamarinepower.com/
Voith Hydro Wavegen Limited	Limpet500	www.wavegen.co.uk
AWS Ocean Energy Ltd	Archimedes Waveswing	www.waveswing.com
Checkmate SeaEnergy	Anaconda	http://www.checkmateuk.com/seaenergy/links.html
C-wave Ltd	C-Wave	www.cwavepower.com/
Dartmouth Wave Energy Limited	Searaser	www.dartmouthwaveenergy.com
Embley Energy	Superboy	www.sperboy.com
FreeFlow 69 Ltd	FreeFlow 69 Wave Pump	www.hi-spec-uk.com/
Green Cat Renewables Ltd	Green Cat Wave Turbine	www.greencatrenewables.co.uk/
Green Ocean Energy	Wave Treader	http://www.greenoceanenergy.com/
Lancaster University Renewable Energy Group	Wraspa	http://www.lancs.ac.uk/fas/engineering/lureg/group_research/wave_energy_research/wras

		pa.php
Manchester Bobber Company Ltd	The Manchester Bobber	www.manchesterbobber.com
Neptune Renewable Energy	The Neptune Triton	www.neptunerenewableenergy.com/wave_technology.php
Ocean Navitas Ltd	Aegir Dynamo	www.oceannavitas.com
Ocean WaveMaster Ltd	Wave Master	www.oceanwavemaster.com
Offshore Wave Energy Ltd	OWEL Grampus	http://www.owel.co.uk/owel.htm
Pelamis Wave Power Ltd	Pelamis	www.pelamiswave.com
Pure Marine Gen Ltd	DUO Wave Energy Converter	www.puremarinegen.com
Sea Energy Associates	SEA Clam	www.seaclam.co.uk
Trident Energy Ltd	Trident Energy DECM	www.tridentenergy.co.uk
Ukraine		
KROK-1	Viacheslav Ovsiankin Wave Electric Power Plant	http://vowepp.com/vowepp_002.htm
USA		
Able Technologies	Electricity Generating Wave Pipe	www.abletechnologiesllc.com
Atmocean Inc	Atmocean	www.atmocean.com
Bourne Energy	OCEANSTAR	www.bourneenergy.com/
Columbia Power Technologies	"Prototype Point Absorbers"	www.columbiapwr.com
Ecomerit Technologies	Centipod	http://www.ecomerittech.com
ELGEN Wave	Horizon	www.elgenwave.com
Float Inc	The Pneumatically Stabilized Platform or PSP	www.floatinc.com
Giggawattz	Giggawattz	http://www.giggawattz.com/
Green Wave Energy Corp	Syphon Wave Generator	http://www.gedwardcook.com/
GyroWaveGen	GyroWaveGen	http://peswiki.com/index.php/Directory:GyroWaveGen(tm)
Independent Natural Resources Inc.	SEADOG	www.inri.us
Kinetic Wave Power LLC	PowerGin	http://www.kineticwavepower.com
SebaiCMET	Modified Magnetic Wave Energy Generator	http://www.sebaicmet.com/index.php?option= com_content&view=section&layout=blog&id=4&Itemid=9
Neo-Aerodynamic Ltd	Wave Unit	http://www.neo-aerodynamic.com/default.html
Ocean Motion International	OMI WavePump	http://www.oceanmotion.ws/
Ocean Power Technology	PowerBuoy	www.oceanpowertechnologies.com
Ocean Wave Energy Company	Ocean Wave Energy Web	www.owec.com
Offshore Islands Limited	Wave Catcher	www.offshoreislandslimited.com
Philsinventions	Deltawave	http://www.philsinventions.com/deltawave.htm
Philsinventions	WaveMower	http://www.philsinventions.com/deltawave.htm
Resolute Marine Energy	"Prototype Point-Absorber "	http://www.resolutemarine.com
SARA Inc.	MHD Wave Energy Conversion (MWEC)	www.sara.com
SeaVolt Technologies	Wave Rider	http://www.seavolt.com/
Solar Inspired Energy Inc.	SIE CAT	www.wave-energy-accumulator.com/
Swell Fuel	LOPF BUOY	www.swellfuel.com/
Waveberg Development Limited	The Waveberg	www.waveberg.com
Liquid Robotics	Wave Glider	http://liquidr.com/
WindWavesAndSun	WaveBlanket	www.windwavesandsun.com

Table 38: World Directory of Wave Energy Companies (European Marine Energy Centre, 2009b, Waveplam, 2009, Pure Energy Systems Wiki)

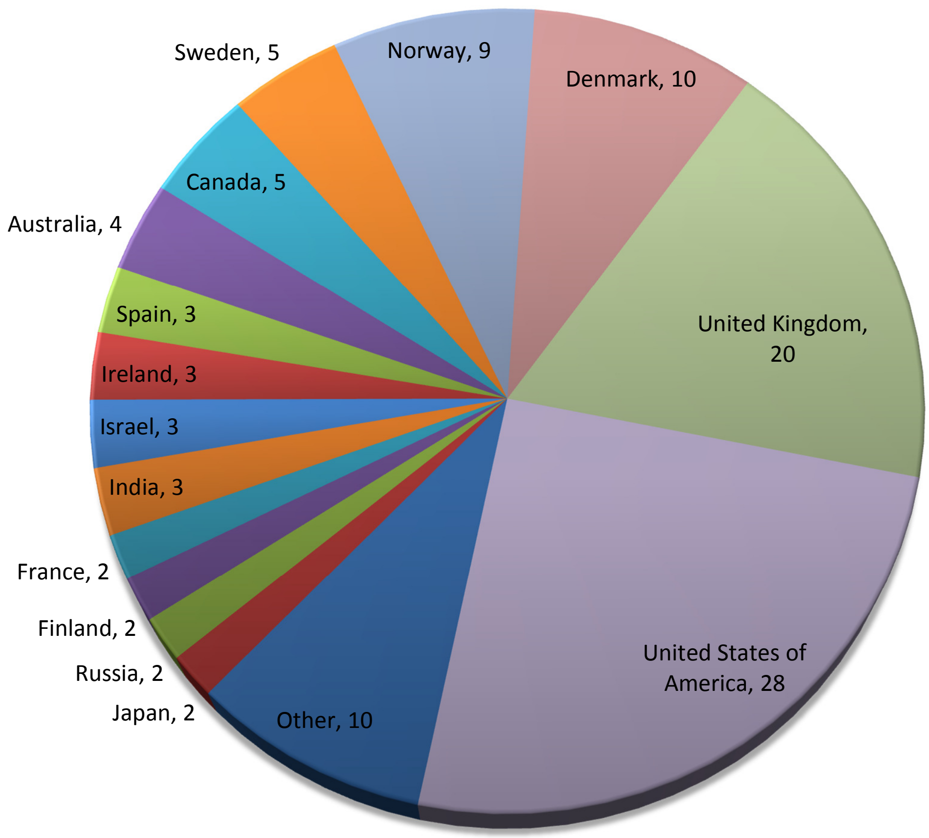


Figure 75: World Wave Energy Companies by Country

As can be seen from Figure 75, the UK has the second greatest number of wave energy device developers behind the USA. It should also be noted that Europe on the whole is currently world leading, holding 60 devices (54% of total) against 51 found elsewhere (46%). Although this list may not be exhaustive and final, (especially given the relatively fast turnover of developer companies) it is certainly illustrative of the fact that the UK is a prominent leader within the sector. This is especially true given the high state of technical advancement that the UK's developers are in and therefore The UK is seen as a major actor internationally within the wave energy sector.

There are several routes to commercialisation of either a technology or device depending upon where the initial concept for the technology is formed. If the technology is developed within a university environment (for example) the individual researcher (entrepreneur) can attempt to commercialise the device (as with Pelamis Wave Power) or the device can be 'spun-out' into a separate company, (as with the Manchester Bobber). Alternatively, if a wholly private entrepreneur and company can try to fully commercialise (such as Dartmouth Wave Energy) or sell/lease out the technology (such as with AWS). The below Figure 76 shows these routes to commercialisation.

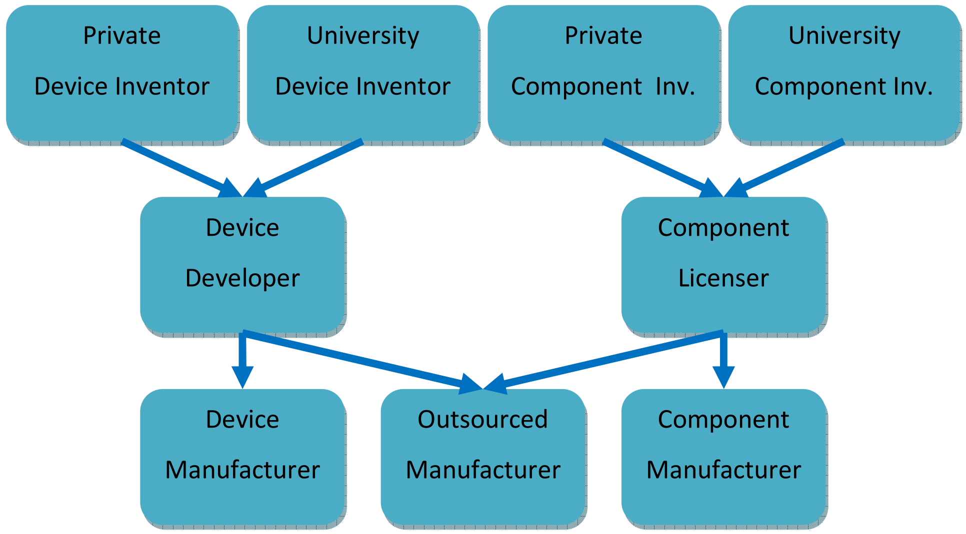


Figure 76: Routes to Technology commercialisation

6.9.3 Universities and Collaboration

One thing that clearly distinguishes the wave energy sector from many others is that, due to the high costs of research and testing facilities as well as heterogeneous knowledge bases required for the commercialisation of the technology (e.g. fluid dynamics, environmental, engineering, electrical) there is a strong development necessity for cross-institutional collaboration (EPSRC, 2009). This is specifically true between device developers and universities that possess both the facilities (test tanks and modelling software) as well as the skills to help develop their concepts and designs. This was not as apparent within the Danish wind industry where testing of devices could be done much more easily and incremental improvements made since installation costs were lower, in-situ access to the technology higher and scalable deployment was possible (Karnøe, 1990, Jørgensen, 1995).

Collaboration with universities also helps to increase the legitimacy of the technology in the eyes of funders, be they public or private due to the perception (as mentioned above) that the technology complexity supports collaborative research. As a result, much of the entrepreneurial experimentation of the sector is being conducted by device developers in conjunction with one or more university as well as the UK test centres (see Market Formation section (6.7.1) of this chapter for examples of cross institutional collaborative networks).

> "It depends upon the ethos of the company however it's very difficult to try and gauge the sector by tank testing time."
>
> University

One of the key indicators of entrepreneurial activity is to assess in-house/tank testing time which the device has undergone (Bergek *et al.*, 2008a). Device developers were therefore asked in question 5(b) to approximate how much tank test time their device had undergone (in hours and at differing scales) since conception. The results for this are shown in Figure 77 below.

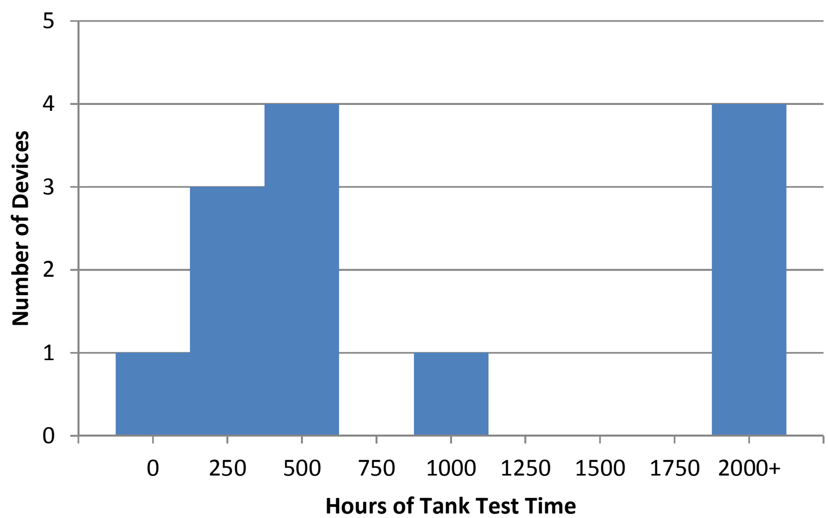


Figure 77: Hours of Tank Test Time Conducted

Most device developers believed that the number of tank tests conducted was itself a poor measure of the level of technical innovation that had occurred, however using non-parametric correlation, (Spearman's rho) there can be shown to be a strong and positive (significant to less than 0.01 in 1-tailed tests) correlation between levels of tank test time and technical maturity as established in the Materialisation section (6.4.4) as can be seen in Table 39 below.

			Device Technical Maturity	Tank Test Time Completed
Spearman's rho	Device Technical Maturity	Correlation Coefficient	1.000	0.642**
		Sig. (1-tailed)	n/a	0.009
		N	14	13
	Tank Test Time Completed	Correlation Coefficient	.642**	1.000
		Sig. (1-tailed)	0.009	n/a
		N	13	13

**. Correlation is significant at the 0.01 level (1-tailed).

Table 39: Correlation between Technology Tank Test Time and Device Technical Maturity

Universities were also asked if they possessed test tanks. 5 of the 14 respondents reported to possessing a test tank capable of wave energy device testing at varying scales and one is currently having a tank installed. This shows that there is fairly adequate provision for model testing by the current number of UK wave device developers.

Some device developers did point out during the interview process that they foresaw specific problems regarding working with universities which had or could deter them from potential collaborations to assist in the commercialisation of their technology. Most notably mentioned issues were:

- Commercial sensitivity of technology: Unsurprisingly, most device developers considered commercial sensitivity to be one of their primary concerns when collaborating with universities, test centres and indeed utility companies. These concerns can clearly be managed through the use of confidentiality agreements as well as contract clauses that pertain to IPR. However, given the high value of IPR for device developers, this maintains as a concern.
- Slow turnaround time: Another point that many device developers made is that although universities are good for non time-critical research such as generic fundamental knowledge generation or future technology optimisation strategies, most work tended to have a slow turnaround time that was unsuitable for 'quick-fix' requirements (such as in-field failure strategies or project deployment critical problem solving). This is somewhat unavoidable given the research structure of most universities, (i.e. long term PhD student positions and multiple use requirements of resources such as staff and equipment.)

> "We tend not to do specific research contracts because it doesn't fit with what we're doing. If something's very important then we would need to do it yesterday!"
>
> Device Developer

- Universities are 'Out of touch with industry': Some developers (although a minority) believe that universities in general were out of touch with the current needs of industrial developers. Specifically with regards to the purchase of capital equipment such as component testing facilities (e.g. test tanks etc.). This is a specific concern for less mature device developers who believe that the costs and facilities available from university institutes are either not necessary, designed without consultation from the sector and are prohibitively expensive to hire/use. This is an interesting finding as it identifies an innovative bottleneck for less mature developers that may be impeding them from producing technically viable devices that are supportable at the full-scale (where £10m+ costs begin to emerge).

The findings of this chapter have provided a strong insight into the current status of the sector and the varying functional processes that are occurring. A detailed description of both the methodological problems encountered while trying to conduct the study as well as a synthesis of these findings (and those from the next chapter, the Additional Findings) are discussed within the last two chapters, Methodological Discussion and sectoral/system Discussion chapters respectively.

6.10 Conclusive Remarks

The Established Findings chapter has explored the wide breadth of proxies/metrics that are currently available and suggested for analysis within existing TIS literature. This has been done through the lens of the TIS and divided conceptually into the eight functionalities as outlined by Bergek. The applicability and methodological complexities encountered while undertaking this research are discussed within the Methodology Discussion chapter (chapter 9) as well as the many integrated narrative findings and discussions regarding the sector itself which are covered within Chapter 10, the System Discussion chapter. The following chapter however, (Chapter 7) compliments this one by exploring primary findings regarding the system through the application of social network analysis. Although the undertaking of this research was done concurrently with this work, the methodology and output findings (again discussed within chapters 9 and 10) are entirely unique and have thus been addressed separately.

Quantifying Methods for an Innovation Systems Analysis of the UK Wave Energy Sector

Submitted by Angus Robert Vantoch-Wood, to the University of Exeter
as a thesis for the degree of
Doctor of Philosophy in Renewable Energy
In October 2012

Volume 2 of 2

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

(Signature) ……………………………………………………………………………………

7. Additional Social Network Analysis Findings and Calculations

Table of Figures:

Table of Tables:

7.1 Chapter Introduction and Overview to Network Analysis

Outcomes from the primary interview stage (after saturation of the snowballing process detailed within the Methodology, Chapter section 5.6.1) secured responses from fourteen out of seventeen active device developers, (with a further three claiming to be no longer operational within the sector), five out of seven utility companies (with a further one, Centrica being the only major utility company not operational within the sector), six out of twelve government bodies including regulatory bodies (with a further three not having a direct operation within the sector, e.g. the Treasury) (the central government departments DECC and the Scottish Government were however interviewed), fourteen out of twenty four universities and research centres (with a further five having no involvement) and all three of the active test centres. This response rate is shown graphically in Figure 78 below:

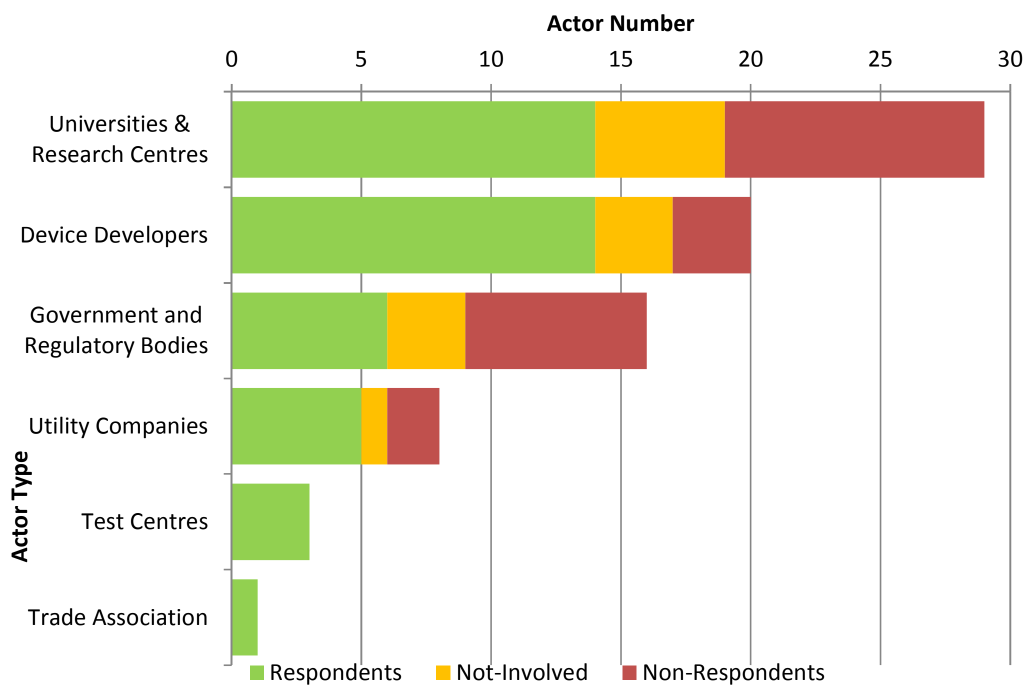


Figure 78: Interview Response Rate

Question 1(a) asked interviewees to list actors which they perceived they had the most interaction with within three separate fields: technical, market/fiscal and environmental and planning. They were also asked to rate the perceived intensity of this interaction from one to ten, (with one being casual and intermittent interaction and ten being an intense and sustained interaction). From the results of this question, a network map was created in which there were a total of two hundred and twenty eight separately referenced actors identified in addition to the forty three interviewed, twenty two non-respondents and twelve non-involved ‘system actors’ (of which six of the ‘non-involved’ were not referenced and therefore removed from the network data maps). This resulted in a total of two hundred and ninety nine separate actors referred within three fields of technical, market/fiscal and environmental/planning. Out of this total, two hundred and twenty one were based within the UK and the remaining seventy eight were from non-UK residency. Using Companies House WebCheck service database (Companies House, 2011) as well as further desktop studies, the addresses for all two hundred and twenty one actors were compiled and converted into longitude and latitude. This was then used as a reference for x and y coordinates and superimposed upon the UK map. The resulting outputs for all three network types are shown below in Figure 79, Figure 80 and Figure 81[1].

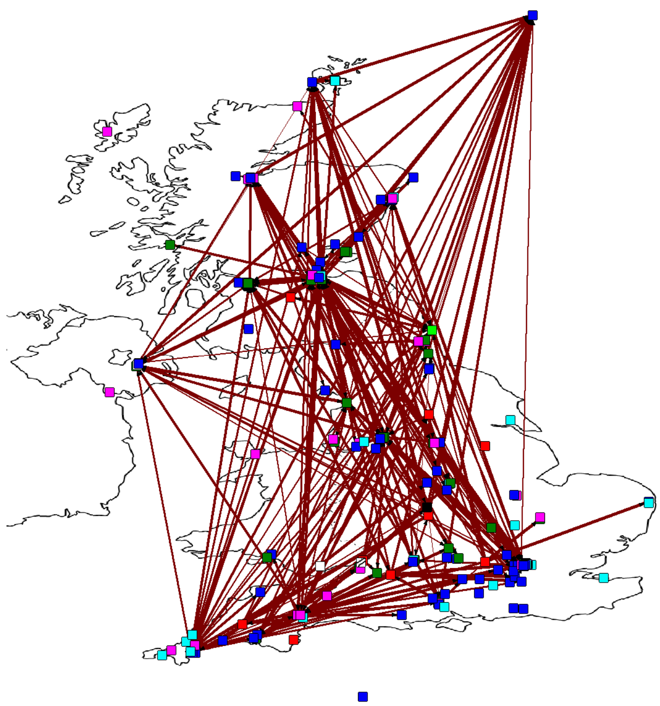


Figure 79: UK Wave Energy Sector (Technical Interactions)

[1] NB. For diagrammatic clarity, non-UK actors have been located at 60° Latitude 0° Longitude (to the top right of the UK)

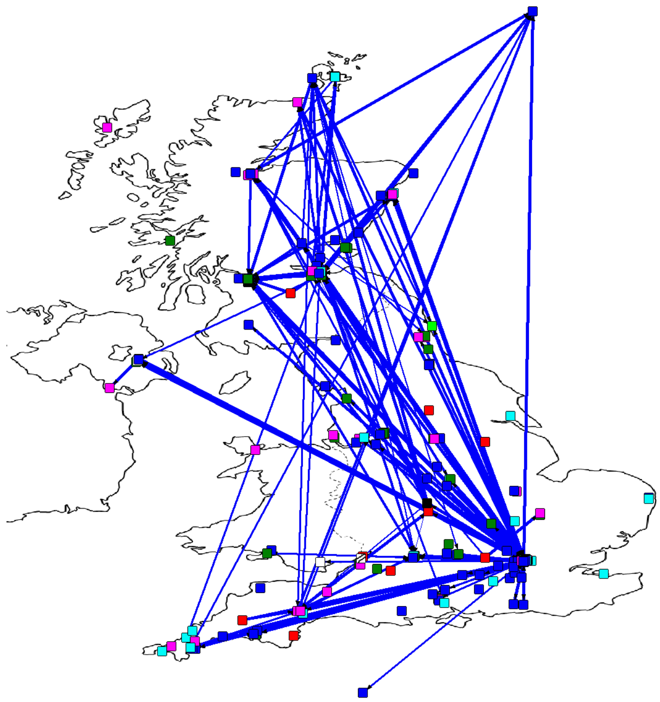


Figure 80: UK Wave Energy Sector (Market/Fiscal Interactions)

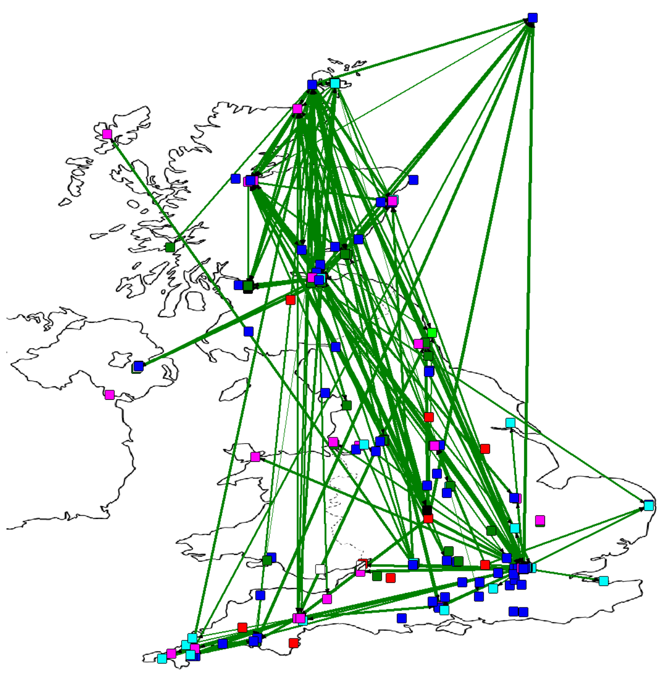


Figure 81: UK Wave Energy Sector (Environmental/Planning Interactions)

The non-respondent rate can be quantified using two methods. The first is that shown above outlining the simple number of respondents, the second however is possibly more insightful as many of the non-respondents are thought to be either not involved or marginally involved within the sector. By summating the amount of overall 'in-ties' obtained from the primary interview stage, (i.e. how many people have referenced non-respondents) we can see how active these non-respondents were by reference of those that did respond as can be seen in both Figure 82 and Figure 83 (for the summated weighted in ties) below:

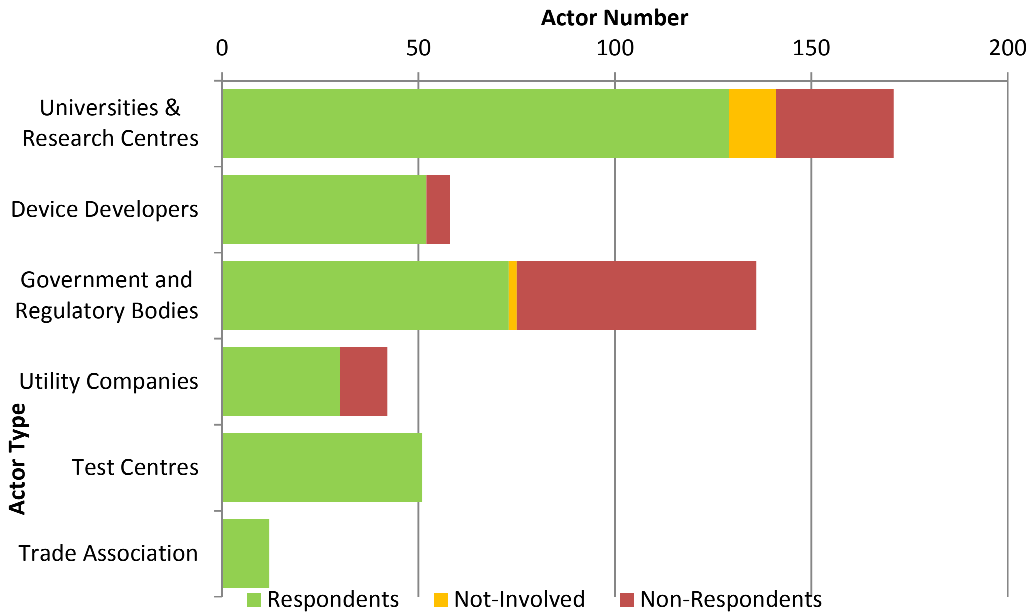


Figure 82: Non-Weighted Respondent In-Ties for Sector

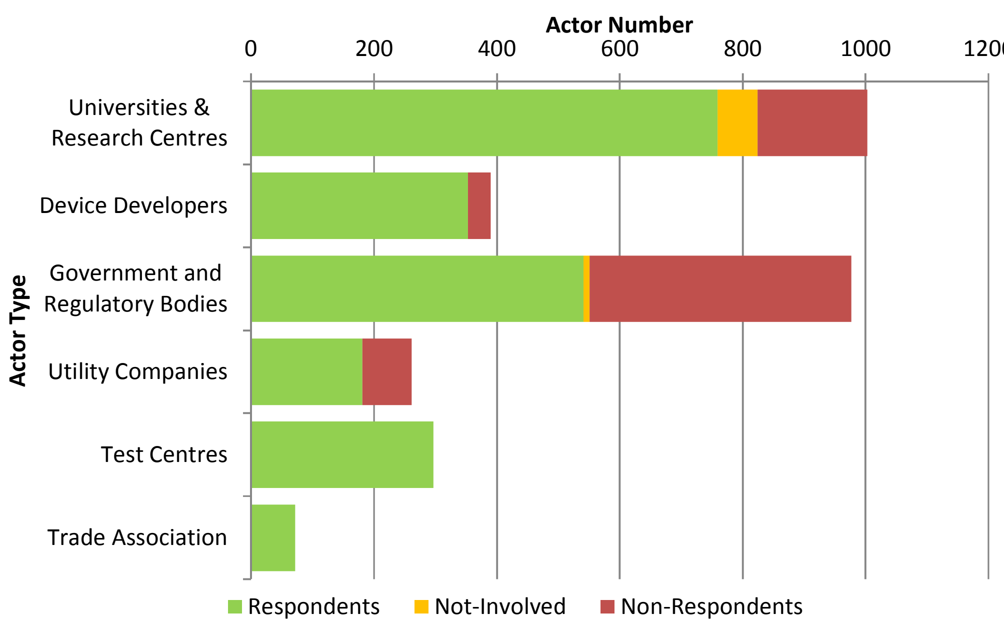


Figure 83: Weighted Respondent In-Ties for Sector

The only clear actor group missing from the interviewed data set as can be seen from Figure 83 are government and regulatory bodies, (specifically the Carbon Trust and Scottish Enterprise who make up a large proportion of the referenced responses).

Although this assessment precludes the prospect of potentially isolated 'cliques' within the data set, (i.e. clusters of non-respondent system actors heavily interacting with each other only) the probability of this occurrence can be roughly assessed by looking at the overall clustering coefficient metrics of the network (as detailed within the Literature Review section 2.4.3b) alongside the average density as shown in Table 40 below. The data used in Table 40 has been modified as explained within section 7.3.1c however it is clear that there is still a very high level of cliquish behaviour when comparing cluster coefficients with average density values. This is not unexpected given the high number of non-system actors who would not be able to indicate (or indeed be likely to have) interactions between each other therefore 'cliquish' topology would be expected since this clique itself makes the system under analysis.

Full Valued (Reciprocal Modified) Network	Avg Value Density	Std Dev	Average Cluster Coefficient	Weighted Cluster Coefficient
Technical	0.0388	0.5212	1.782	0.575
Market	0.0312	0.4973	3.378	1.63
Environmental	0.0255	0.4327	2.207	0.732
Summated	0.0955	0.9085	3.501	0.911

Table 40: Cluster Coefficients of the Network

7.1.1 Primary Attributes

In addition to the 3 relationship matrices compiled and shown in the above diagram, twenty primary attributes were collated for all stakeholders in a separate attribute database and are described as follows:

Company:

This is a simple identifier for the actor name (and was also the only ASCII input allowed due to the software (ucinet) validity checker.

Simple Tax & Adv Tax:

These numbers equate to actor type taxonomies assigned to every stakeholder (system and non-system actors) for the purpose of assessing the makeup of networks as well as entrepreneurial agents as shown in Table 41:

Simple Taxonomy	Advanced Taxonomy	Companies (1)
		Direct Device Manufacturer (a)
1	1	Final Device Developer Company (i)
2	2	Structural Component Supplier Company (ii)
2	3	Electrical Component Supplier Company (iii)
2	4	Mooring Component Supplier Company (iv)
2	5	Mechanical Component Supplier Company (v)
2	6	Other (vi)
		Site Developers (b)
2	7	Project Management Consultancies/Companies (i)
2	8	Electrical Consultancies/Companies (ii)
2	9	Marine Engineering Consultancies/Companies (iii)
2	10	Onshore Civil Engineering Consultancies/Companies (iv)
2	11	Offshore and Embedded Civil Engineering Consultancies/Companies (v)
2	12	Operations and Maintenance Companies (vi)
2	13	Environmental Consultancy Companies (vii)
2	14	Legal/Planning Consultancy Companies (viii)
2	15	Fiscal Consultancy Companies (ix)
2	16	Other (x)
		Electricity Companies (c)
3	17	Supplier Company (i)
2	18	Transmission/Distribution Company (ii)
2	19	Other (iii)
		Miscellaneous (d)
2	20	Fiscal Support Bodies (i)
2	21	Trade Associations (ii)
2	22	Renewable/Wave/Tidal Media Bodies (iii)
2	23	Other (iv)

Simple Taxonomy	Advanced Taxonomy	Public Sector Bodies (2)
4	24	Central Government Departments (a)
5	25	Management/Licensing & Regulatory Bodies (b)
5	26	Regional/Government Departments & Agencies (c)
5	27	European or International Department or Project (d)
5	28	Renewable Specific Support Agencies and QuANGOs(e)
5	29	Other (f)

Simple Taxonomy	Advanced Taxonomy	Research Bodies (3)
		Academic (a)
6	30	Universities (i)
6	31	Other (ii)
6	32	Industry Research Bodies (b)
7	33	Test Centres (c)
6	34	Other (d)

Simple Taxonomy	Advanced Taxonomy	Collaborative Affiliations (4)
8	35	Wave/Tidal Specific Industry Network (a)
8	36	Renewable Industry Networks (b)
8	37	Marine Stakeholder Networks (c)
8	38	Wave/Tidal/Renewable Academic Network (d)
8	39	Other (e)

Table 41: Simple and Advanced Actor Type Taxonomy

Code	Stakeholder Type	Quantity
1	Final Device Developer	23
2	Other Company	107
3	Utility Company	9
4	Central Government Department	12
5	Other Public Sector Department	40
6	University	67
7	Test Centre	3
8	Collaborative Affiliations	38

Table 42: Simple Actor Taxonomy Quantities

SIC Code:

Standard Industrial Classification codes were retrieved for all stakeholders (system and non-system actors) who were registered as non-exempt UK businesses (both 03 and 07 codes as registered by the business), again for the purpose of assessing the makeup of networks as well as entrepreneurial agents through the nature of their economic activity (Companies House, 2011).

System Actors:

A numeric code was assigned to identify four different system actor types for the purpose of assisting in validation of the overall system boundary, (i.e. identifying how core to the network identified system actors were) shown in Table 43:

Codes:	Description:
1	Non-System Actor (referenced)
2	System Actors' Not Directly Involved in Sector
3	System Actor (referenced not Interviewed)
4	System Actor (Interviewed)

Table 43: System Actor Type

No of Networks:

As identified through the Market Formation section of the Established Findings chapter, the number of wave energy sector networks in which each stakeholder was a member of was summed and the number assigned to this value (for both system and non-system actor).

Longitude & Latitude:

Longitudinal and latitudinal data was found for each UK based stakeholder through firstly identifying their registered company office (through Companies House) and then converting the corresponding postcode. This was done to allow geographical and cross geographical comparisons of activity (i.e. regional/ national/ international) such as identification of local hubs of activity etc.

Nationality:

This is a simple taxonomy used to identify levels of national/international activity as well as identify the overall geographic makeup of the network. Numbering is shown in Table 44:

Code	Nationality	Quantity
1	English	151
2	Scottish	61
3	Welsh	78
4	N. Ireland	5
5	International	4

Table 44: Nationality Code

Company Number:

This is a simple identifier number assigned to all system actors for analysis purposes (since Ucinet software does not accept ASCCI code for attribute data).

Device Type:

The type of device developer technology was identified for all system device developers as shown in Table 45:

Code	Device Type (Based on IPC)
1	Overtopper
2	OWC
3	Semi-Fixed or Fixed
4	Non-Fixed

Table 45: Device Developer Type Code

Tech Maturity:

The level of device technology maturity was identified for all system device developers using the technology maturity table shown in Table 46 below:

	Step Descriptions:	Step Location:	#
R&D:	**Applied & Strategic Research**		
	Basic principles observed and reported	Concept for a Wave or Tidal Energy Converter	1
	Technology concept and/or application formulated	Concept for a Wave or Tidal Energy Converter	2
	Analytical and experimental critical function and/or characteristic proof of concept	Utilise Research Providers (Universities etc.)	3
	Component and/or partial system validation in a laboratory environment	Develop Design Utilising Engineering Expertise	4
	Technology Validation		
	Component and/or partial system validation in a relevant environment	Tank Testing	5
	System/subsystem model validation in a relevant environment	Scale Test Facilities e.g. NaREC	6
Demonstration:	**System Validation**		
	System prototype demonstration in an operational environment	Full Scale Test Facilities - EMEC	7
	Actual system completed and service qualified through test and demonstration	Full Scale Test Facilities - EMEC	8
	Actual system proven through successful mission operation	Full Scale Test Facilities - EMEC	9
Pre-Commercial:	**Commercial Validation**		
	Singular system 'commercially' deployed on successful long term grid connected installation	Pre-Commercial Deployment - EMEC/Wave Hub	10
	Small arrays (<10MW or 20 devices) 'commercially' deployed on successful long term grid connected installation	Pre-Commercial Deployment - Wave Hub/Pentland Firth	11

Table 46: Technology Maturity (Based on TRL Level) of UK Wave Energy Devices

Technical, Market, Environmental and Planning and Other Employees:

Identified through the primary research phase, these four indicators are the reported amount of FTE employees that each interviewed system actor reported to employ within the three different knowledge field categories as well as an 'other' section for non-specific support staff who were considered to be working full time within the sector, (such as administrators etc.). This figure includes FTE postgraduate researchers.

Technical, Market, Environmental and Planning Postgraduates:

Again, Identified through the primary research phase, these three indicators are the reported amount of FTE postgraduate (PhD and Masters) students that each university system actor reported to support within the three different knowledge field categories within the sector.

7.1.2 Overview Statistics

Reported levels of interactions: (Taken from the interactive dichotomisation) are shown in Table 47 below.

Data Value	Z-Score	Frequency	Separation	Number at or above	Density
0	-0.047	88882		89102	1.000
1	2.841	2	0.942	220	0.002
2	5.730	9	0.945	218	0.002
3	8.618	14	0.953	209	0.002
4	11.506	25	0.958	195	0.002
5	14.395	24	0.952	170	0.002
6	17.283	29	0.931	146	0.002
7	20.171	23	0.884	117	0.001
8	23.060	39	0.826	94	0.001
9	25.948	33	0.674	55	0.001
10	28.836	22	0.453	22	0.000

Table 47: Overview Levels of Interactivity

As can be seen from the table and z-scores, the vast majority of (>99%) of interactions are of level 0. This is not only expected but given that the vast majority of network nodes are non-respondents, would not be anything less.

7.2 Influence upon the Direction of Search

7.2.1 Internal Technology Group Influences

When filing a patent, the applicant must cite all documents (patents) from which the initial idea has been drawn upon. This is particularly useful when seeking to apply a network analysis approach to patent innovation as it provides a direct line of chronological influence from which to create a network resulting in a 'family tree' of patents.

As described within the methodology, patents within the wave energy sector were identified under the overarching classification F03B13/14 to /24 (European Patent Office, 2010). From searching for GB patents within this classification, a total of 512 patents were identified and processed to extract a relationship matrix (from the cited documents data) as well as other attribute data for each patent. This attribute data included:

- Publication name, simply for referencing
- Date of application, (which was converted into YYYYMMDD format to allow for analysis)
- Patent sub-classification type. Which was valued as:

Non Wave Energy Device	7
Non-Specific	1
Relative Movement	2
Fixed/Semi-Fixed	3
Non-Fixed	4
Overtopper	5
OWC	6

Table 48: Patent Classification Numbering

From this data the networks shown in Figure 84 (Isolates and all small sub-groups) as well as Figure 85 (main component network) were created, (N.B. Disconnected nodes along the far left side are isolates in that they do not reference any other node):

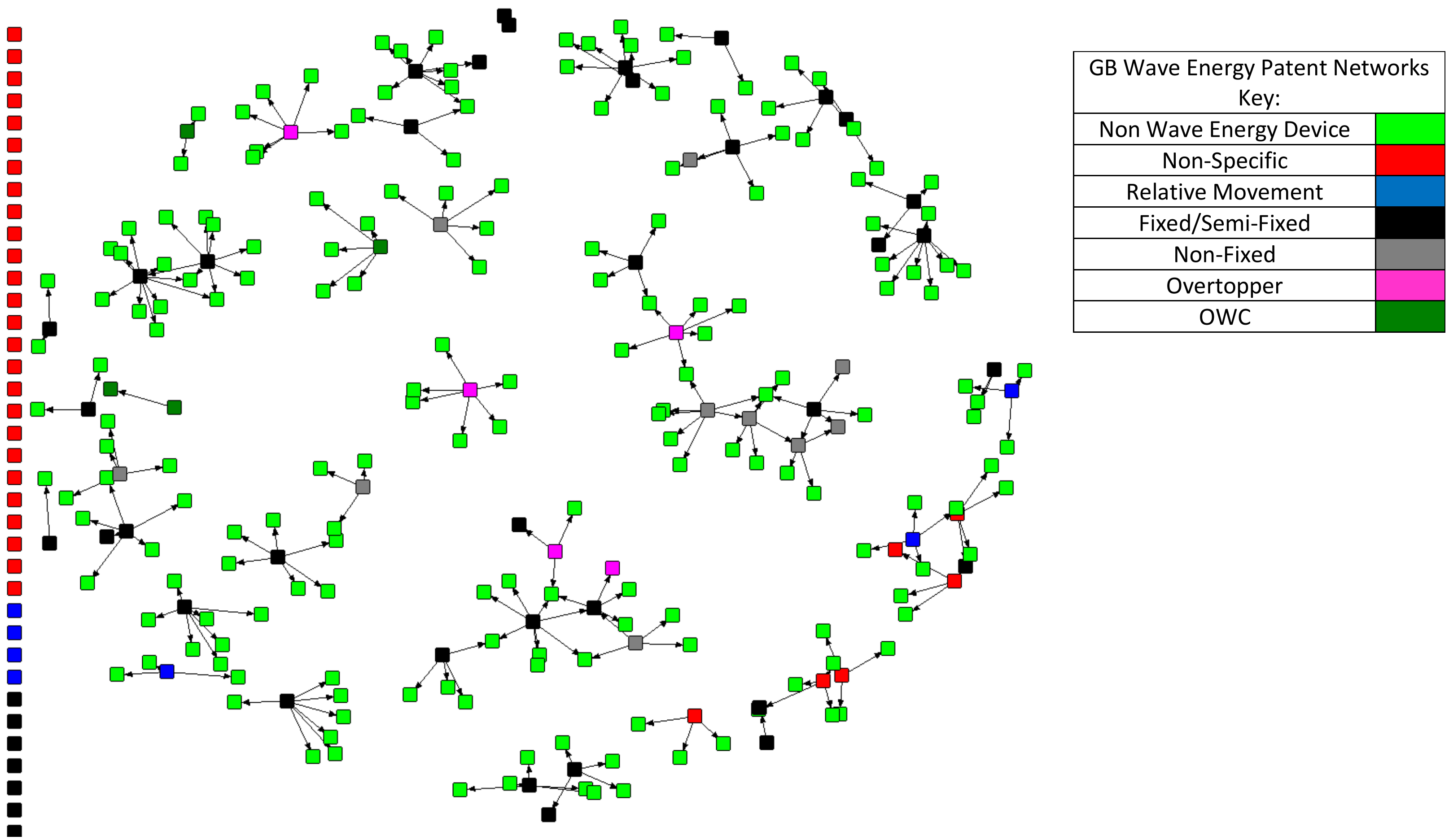


Figure 84: GB Wave Energy Patent (F03B13/14</24) Isolate and Periphery Groupings Network

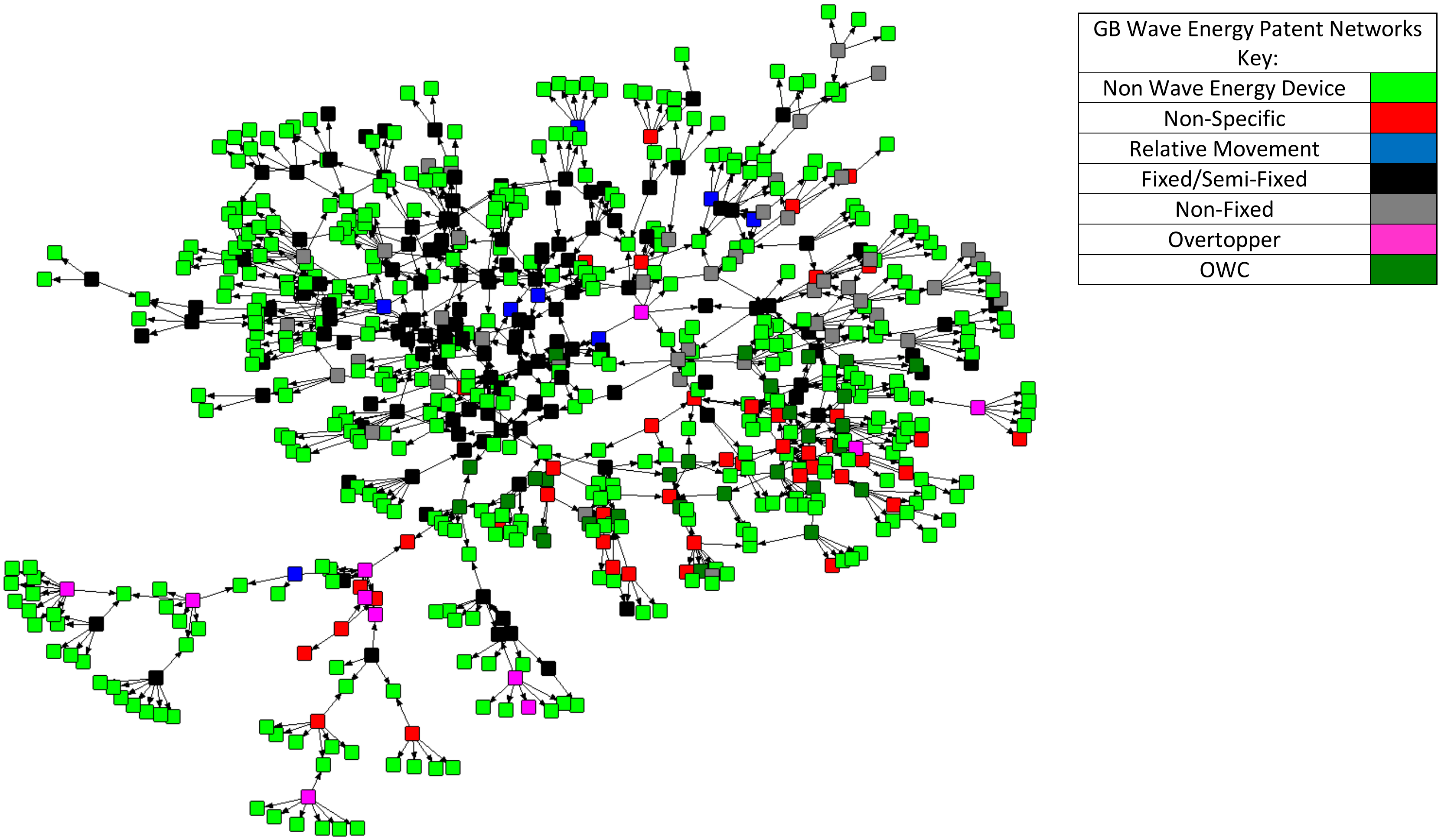


Figure 85: GB Wave Energy Patent (F03B13/14</24) Main Component Group Network

From Figure 84 and Figure 85 it can be identified that there are 176 isolates (all of which are clearly wave energy patents that have not cited any other patent) as well as 250 small group patents, (65 of which are wave energy patents) and 685 patents within the main core network (inclusive of the remaining 271 wave energy patents. In addition to the 512 wave energy devices there are therefore a total of 599 non-wave energy devices referenced making a total data set of 1111 patents as shown in Table 49 and Table 50 below.

	Isolate Numbers	Sub Group	Main Set
Non Wave Energy Device	0	185	414
Non-Specific	26	6	44
Relative Movement	4	3	8
Fixed/Semi-Fixed	98	37	134
Non-Fixed	26	10	44
Overtopper	9	5	11
OWC	13	4	30
Total Wave Only:	176	65	271
Total:	176	250	685

Table 49: Wave Energy Patent (F03B13/14</24) Sub-Group Technology Type Breakdown

	Isolate Numbers	Sub Group	Main Set
Non Wave Energy Device	0%	31%	69%
Non-Specific	34%	8%	58%
Relative Movement	27%	20%	53%
Fixed/Semi-Fixed	36%	14%	50%
Non-Fixed	33%	13%	55%
Overtopper	36%	20%	44%
OWC	28%	9%	64%
Total Wave Only:	34%	13%	53%
Total:	16%	23%	62%

Table 50: % of Wave Energy Patents (F03B13/14</24) per Sub-Group by Technology Type

Visually, it can be seen clearly in Figure 85 that there is some level of cohesion between differing sub groups of patents, particularly fixed/semi-fixed (in black) and oscillating water column (dark green) devices.

For a historical analysis, the data can be presented along a chronological axis as in Figure 86[2].

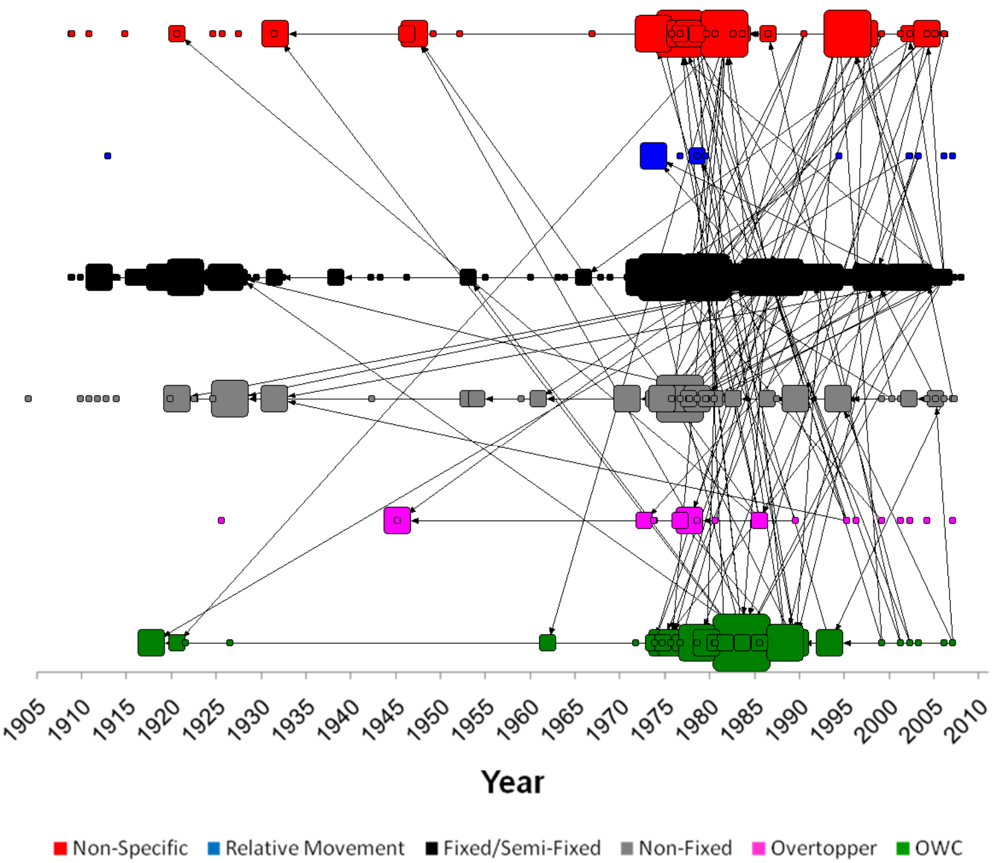


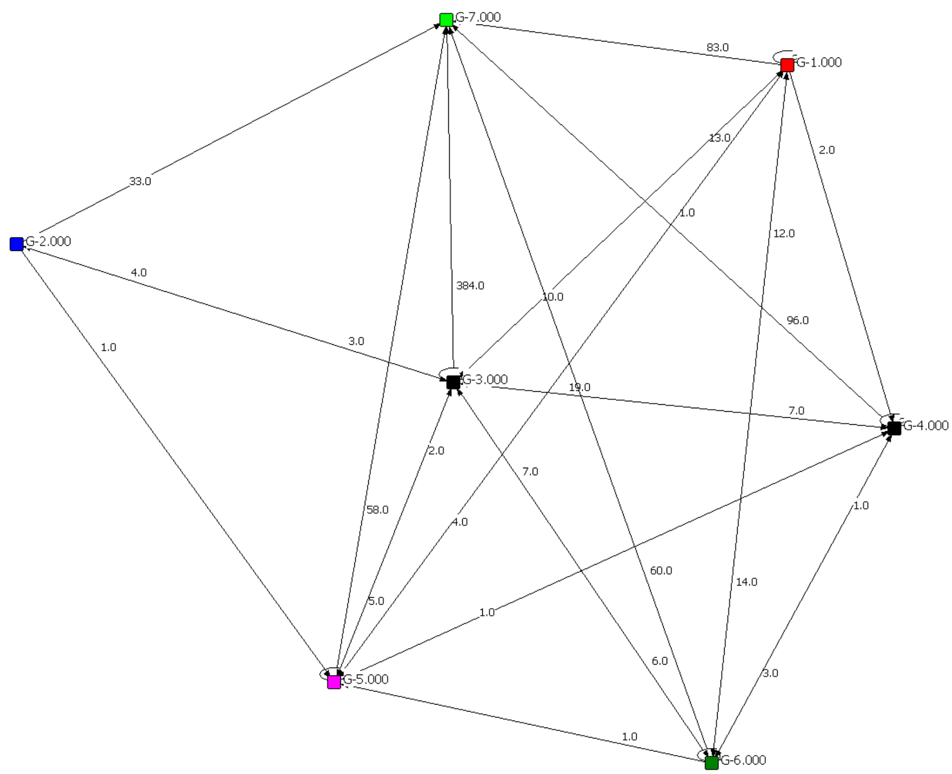
Figure 86: GB Wave Energy Patents (F03B13/14</24) Over Time

The size of the patent in this graph represents the level of ‘In Degrees’, this is a simple measure of the number of later patents that directly reference this patent. It can clearly be seen that there are ‘spurts’ of patenting specifically at the early part of the 1980s (among all sub-groups), as well as the start of the 21st century and, perhaps more surprisingly, some from the 1920s. What the network analysis provides however is a measure of the influence that these patents have had. The lines of ‘influence’ along this chronological path show that there is clearly some inference of cohesion among technology types starting from the 1920s (i.e. the straight lines in each technology type) but also between technology types, specifically this is evident between fixed/semi-fixed patents of the 80s influencing almost all other sub-groups after this time, non-fixed devices influencing fixed-semi-fixed devices from the 80’s onwards

[2] This data excludes all non-wave energy patents for clarity as well as isolates which clearly have neither influence or are influenced by other devices.

and OWC and non-specific devices from the 80s also having a great deal of influence upon fixed-non-fixed devices of the 1980's. Overtoppers and relative movement devices are clearly more isolated and have had less influence upon the over patent culture within the sector.

If nodes are collapsed into 'supernodes' categorised by wave device type, the network presented in Figure 87 allows us to analyse the overall levels of influence each patent technology type has had upon the overall technology.



GB Wave Energy Patent Networks Key:	
Non Wave Energy Device	
Non-Specific	
Relative Movement	
Fixed/Semi-Fixed	
Non-Fixed	
Overtopper	
OWC	

Figure 87: Wave Energy Patent Technology Type 'Supernodes'

In this diagram, the tie strength represents the frequency of patent citation from each technology type to each other. This was then tabulated to see which technology types have had the most absolute historic influence and upon each technology type (i.e. the sum total of specific citations) as well as the relative level of influence each technology type has had specifically upon each other technology type (by simply dividing the number of citations from/to each technology type by the total number of citations made by the specific technology). Note that the technology types are self-referencing as patents within a technology type are clearly influenced by others within their own patent sub-set.

These can be seen in Table 51 and Table 52.

		Cited Technology Type						
		Non-Specific	Relative Movement	Fixed/Semi-Fixed	Non-Fixed	Overtopper	OWC	Non Wave Energy
Technology Type	Non-Specific	20	0	13	2	1	12	83
	Relative Movement	0	0	4	0	1	0	33
	Fixed/Semi-Fixed	10	3	112	19	2	7	384
	Non-Fixed	0	0	7	26	14	1	96
	Overtopper	4	0	5	1	3	0	58
	OWC	14	0	6	3	1	18	60
	Non Wave Energy	na	na	na	na	na	na	na
	Total Levels of Citation	48	3	147	51	22	38	714

Table 51: Absolute Wave Energy Technology Sub-Types Cited by Technology Sub-Type

		Cited						
		Non-Specific	Relative Movement	Fixed/Semi-Fixed	Non-Fixed	Overtopper	OWC	Non Wave Energy
Technology Type	Non-Specific	15%	0%	10%	2%	1%	9%	63%
	Relative Movement	0%	0%	11%	0%	3%	0%	87%
	Fixed/Semi-Fixed	2%	1%	21%	4%	0%	1%	72%
	Non-Fixed	0%	0%	5%	18%	10%	1%	67%
	Overtopper	6%	0%	7%	1%	4%	0%	82%
	OWC	14%	0%	6%	3%	1%	18%	59%
	Non Wave Energy	na	na	Na	na	na	na	na

Table 52: Relative Wave Energy Technology Sub-Types Cited by Technology Sub-Type

From here also we can identify the total levels of influence that each technology sub-type has had upon the entire wave energy patenting category (as a percentage) by dividing the specific total levels of citation per technology type by the total levels of citation overall. We can also identify the average overall number of citations per technology type, (simply by dividing the number of citations made by a technology type by the number of patents within the technology type) as well as the average amount of influence (i.e. citations), by dividing the number of times the technology type was referenced overall by the number of patents within the technology type. The product of these calculations can be seen in Table 53 below.

		Average Number of Citations per Patent	Average Level of Influence (Citations) per Patent	Total Levels of Technology Influence
Technology Type	Non-Specific	0.58	0.63	5%
	Relative Movement	0.39	0.20	0%
	Fixed/Semi-Fixed	0.50	0.55	14%
	Non-Fixed	0.56	0.64	5%
	Overtopper	0.35	0.88	2%
	OWC	0.46	0.81	4%
	Non Wave Energy	na	1.19	70%

Table 53: Average Levels of Citation and Influence per Patent and Total levels of Influence per Technology Type

As can be seen in Table 53, non-wave energy related patents have clearly had the largest singular level of influence upon the sector. Internally however, 14% of all *cited* patents have been influenced by fixed/semi-fixed patents. This influence was mainly to other fixed/semi-fixed patents, (showing a therefore higher level of cohesion among this technology type then all others). Other notable facts are that both overtoppers and relative movement devices have neither had a large level of influence upon wave energy technologies nor have they used other wave energy types within their search heuristic (however out of all technology types, fixed/semi-fixed have still had the highest level of overall influence upon these sub-categories.)

Another measure of influence that can be used for the wave energy technology types is that of group centrality. Group centrality is a measure of centrality of a sub-set of the whole group with respect to the individuals within the rest of the network (Everett and Bogatti, 2005). Within the context of this analysis, it can be defined as the number of GB wave energy patents (exclusive of the technology group being assessed, i.e. the specific group) that cite the technology group in question. Usually this would be given as:

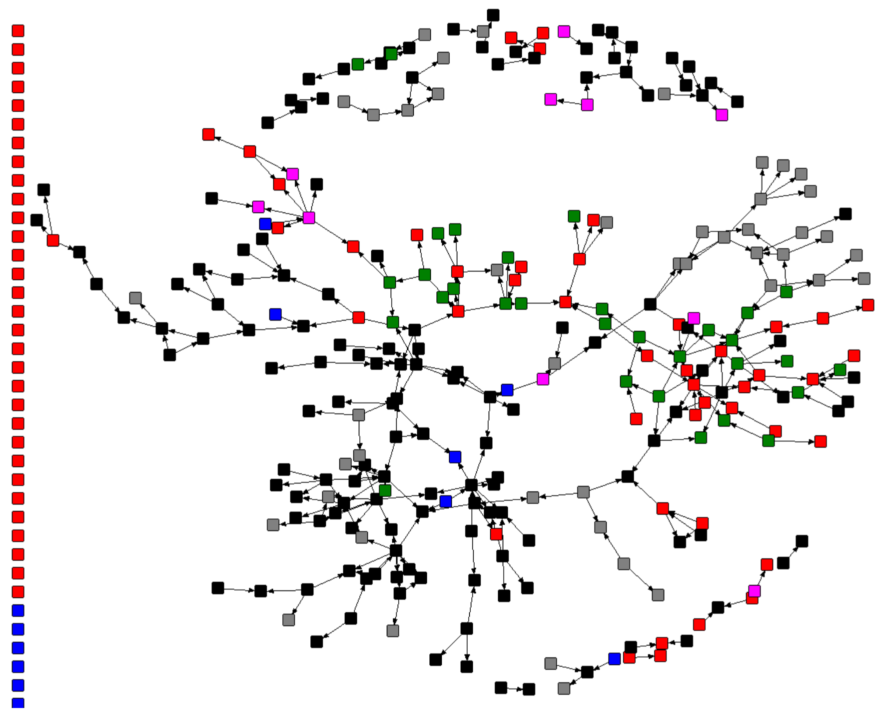
$$Group\ Centrality = \frac{|N(C)|}{|V| - |C|}$$

Where $|V|$ = the entire matrix, (i.e. all of the wave energy patents, 512).

$|C|$ = the subset group of the matrix, (i.e. the technology group being assessed, for example all OWC patents would be 47).

$|N(C)|$ = the non-normalised group centrality which is a measure of the number of *actors* (not ties) that are connected to the group $|C|$, (i.e. the number of individual patents that are referenced by the technology group).

Since non-wave energy patents are not being assessed (and have not been influenced by the wave energy sector) this sub-group is removed for this analysis leaving the network as shown in Figure 88 below.



GB Wave Energy Patent Networks Key:	
Non Wave Energy Device	
Non-Specific	
Relative Movement	
Fixed/Semi-Fixed	
Non-Fixed	
Overtopper	
OWC	

Figure 88: Wave Energy Patent Groups to be Assessed in Group Centrality Measure

Results are from the analysis are shown in Table 54 below.

		Out Deg	Norm. Out Deg	In Deg	Norm. In Deg
Technology Type	Non-Specific	7	1.61%	24	5.50%
	Relative Movement	12	2.41%	11	2.21%
	Fixed/Semi-Fixed	20	8.23%	25	10.29%
	Non-Fixed	18	4.17%	9	2.08%
	Overtopper	16	3.29%	1	0.21%
	OWC	22	4.73%	4	0.86%

Table 54: Raw and Normalised Levels of Group Centrality

Table 54 in degree varies from Table 51 in three fundamental ways. Firstly, it counts only references external to the technology group, (i.e. no reflexive ties). Secondly, no non-wave energy device patents are included and thirdly, the degree count is a count of *patents* cited rather than *citations* itself (e.g. three technology group patents citing one external patent would equal one rather than three). Effectively this is therefore a measure of the internal inter-patent grouping influence that wave energy patent groups have had upon each other rather than the amount of citations that each sub group has referenced the other upon.

7.2.2 Individual Technology Search Heuristic

When assessing the singular patent levels of influence, the most influential patents are simply those that have the highest level of 'in-centrality'. There are however several measures of centrality appropriate for a disjointed network such as this, as discussed in the SNA measures section (2.4.2a) of the literature review.

These calculated scores are given below for the top three most influential patents within each centrality ranking system:

		Patent	In Deg.	In 2 Local	In Harm. Close.	Out Deg.	Out 2 Local	Out Harm. Close.	Bet. Dir	Wave Device Type
In Degree Centrality	1st	EP0035346A2	5	2	5	0	0	0	0	7
	1st	US3961863A	5	2	6	0	0	0	0	7
	1st	GB2161544A	5	8	8	3	1	3.5	30.6	6
In 2 Local Degree Centrality	1st	US4098081A	3	10	8.5	0	0	0	0	7
	2nd	US4466244A	3	9	9	0	0	0	0	7
	3rd	GB2161544A	5	8	8	3	1	3.5	30.6	6
In Harmonic Closeness	1st	US4466244A	3	9	9	0	0	0	0	7
	2nd	US4098081A	3	10	8.5	0	0	0	0	7
	3rd	GB2161544A	5	8	8	3	1	3.5	30.6	6
Between-ness	1st	GB2143284A	4	5	6	11	7	11.5	82.3	1
	2nd	GB2245031A	3	0	3	7	22	16	64.5	6
	3rd	GB2314124A	2	1	2.5	5	14	10.5	45	1

Table 55: Individual Patent levels of Centrality

Individually this means that the patents that have the highest level of centrality and thus influence within the sector can be collapsed into the 8 patents listed in Table 56 below.

In Deg.	In 2 Loc.	Harm. Closeness.	Betweenness.	Title	Publication date	Inventor(s)	Applicant(s)
1st	-	-	-	Wave energy converters.	09/09/1981	FARLEY FRANCIS JAMES MACDONALD	SECR DEFENCE BRIT [GB]
1st	-	-	-	Water action powered pump	08/06/1976	HOOPER III LEE EZEKIEL	HOOPER III LEE EZEKIEL
1st	3rd	3rd	-	Wave power generating apparatus of air-circulating type	15/01/1986	WATANABE KUNIYA	TOHOKU ELECTRIC POWER CO
-	1st	2nd	-	Tidal power plant and method of power generation	04/07/1978	WOODMAN HARVEY R	WOODMAN HARVEY R
-	2nd	1st	-	Power generation	21/08/1984	WU JIUN-TSONG	WU JIUN TSONG
-	-	-	1st	Energy conversion apparatus	06/02/1985	PEATFIELD ANTHONY MICHAEL ET AL.	PEATFIELD ANTHONY MICHAEL
-	-	-	2nd	Wave power resonance generator	18/12/1991	ROWAN DENIS JOSEPH ET AL.	ROWAN DENIS JOSEPH ET AL.
-	-	-	3rd	Wave energy converter	17/12/1997	WELLS ALAN ARTHUR	APPLIED RES & TECH [GB]

Table 56: Most Influential Patents Within the GB Wave Energy Sector

It should also be noted that since there is no weighting for chronology to the network analysis, older patents are clearly the most influential since they have had a longer time to influence newer patents however in practice these older patents may no-longer be as influential as more current technologies.

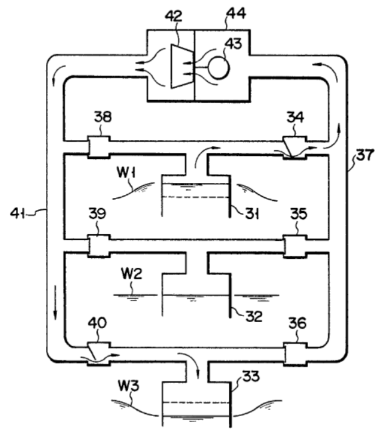


Figure 89: Mosaic Diagram From One of the Most 'Influential' Patents Within the Wave Energy Sector (Watanabe, 1986)

7.3 Knowledge Generation and Diffusion

7.3.1 Individual Stakeholder Knowledge Generation and Diffusion

7.3.1a Individual Stakeholder Degrees Centrality

When applying a network analysis to the interview data to assess where the internal stakeholder knowledge diffusion is occurring, the most obvious measure is that of weighted in degree centrality as this is considered a direct and valued measure of how much knowledge reference a node has. This measure is one of the most obvious identifiers of what are referred to as 'prime movers' within innovation studies (Jacobsson and Johnson, 2000) and as 'leaders' or simply 'influential' actors within SNA (Hanneman and Riddle, 2005, Valente, 2005).

Since the stakeholder network is multidimensional, this measure can apply to all three networks to assess who the most central within each field of knowledge is. Results from this analysis are shown in Table 57 below:

Company	Rank	Enviro W In	Adv Tax
Crown Estates	1st	82	25
Marine Scotland	2nd	78	24
EMEC	3rd	70	33
Scottish Natural Heritage	4th	53	25
Department for Energy and Climate Change	5th	49	24

Company	Rank	Enviro In	Adv Tax
Crown Estates	1st	12	25
Marine Scotland	2nd	10	24
EMEC	3rd	10	33
Scottish Natural Heritage	4th	7	25
Department for Energy and Climate Change	5th	6	24
Aquatera	5th	6	13
Xodus	5th	6	13

Company	Rank	Tech W In	Adv Tax
University of Edinburgh	1st	101	30
University of Manchester	2nd	71	30
University of Strathclyde	3rd	64	30
narec	4th	57	33
Queen's University Belfast	5th	56	30

Company	Rank	Tech In	Adv Tax
University of Edinburgh	1st	17	30
University of Manchester	2nd	12	30
narec	3rd	11	33
University of Strathclyde	4th	10	30
University of Exeter	4th	10	30

Company	Rank	Market W In	Adv Tax
Department for Energy and Climate Change	1st	82	24
Carbon Trust	2nd	69	28
Scottish Enterprise	3rd	63	24
Scottish Government	4th	56	24
Aquamarine Power	5th	49	1

Company	Rank	Market In	Adv Tax
Department for Energy and Climate Change	1st	12	24
Carbon Trust	2nd	10	28
Scottish Enterprise	3rd	9	24
Scottish Government	4th	7	24
Scottish Renewables	4th	7	36
Renewable UK	4th	7	35

Table 57: Measures of Simple and Weighted In Centrality within the UK Wave Energy Sector

Table 57 also shows some striking polarisation within the different measures of centrality. Although weighted and un-weighted measures of centrality show very similar central actors within each network, (an interesting finding in its own right since it suggests that a simplified data gathering method would produce a like-wise if non-parametric result), there is very little multiplexity between networks, (i.e. very few actors are considered central between different networks. The only exception to this being DECC who appear on both the market and environmental network centrality rankings (1st and 5th respectively).

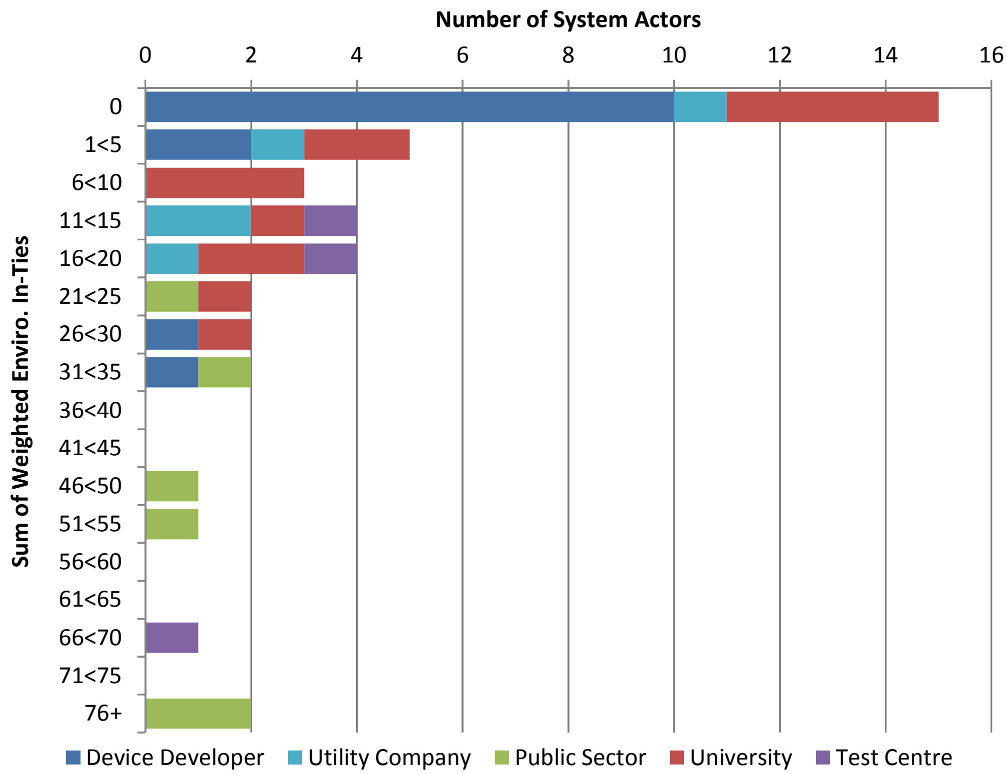
Within the environmental centrality rankings, the Crown Estates provides the highest knowledge/influence within the network. This is not surprising given its role as the primary licensing and management body for the UK waters and seabed. There is also a consistent make-up of environmental licensing and statutory consultees as would be expected as well as the full scale device test site EMEC (only just creeping in at the bottom of the weighted input scale) and the two primary environmental consultancy networks, Xodus Aurora and Aqatera.

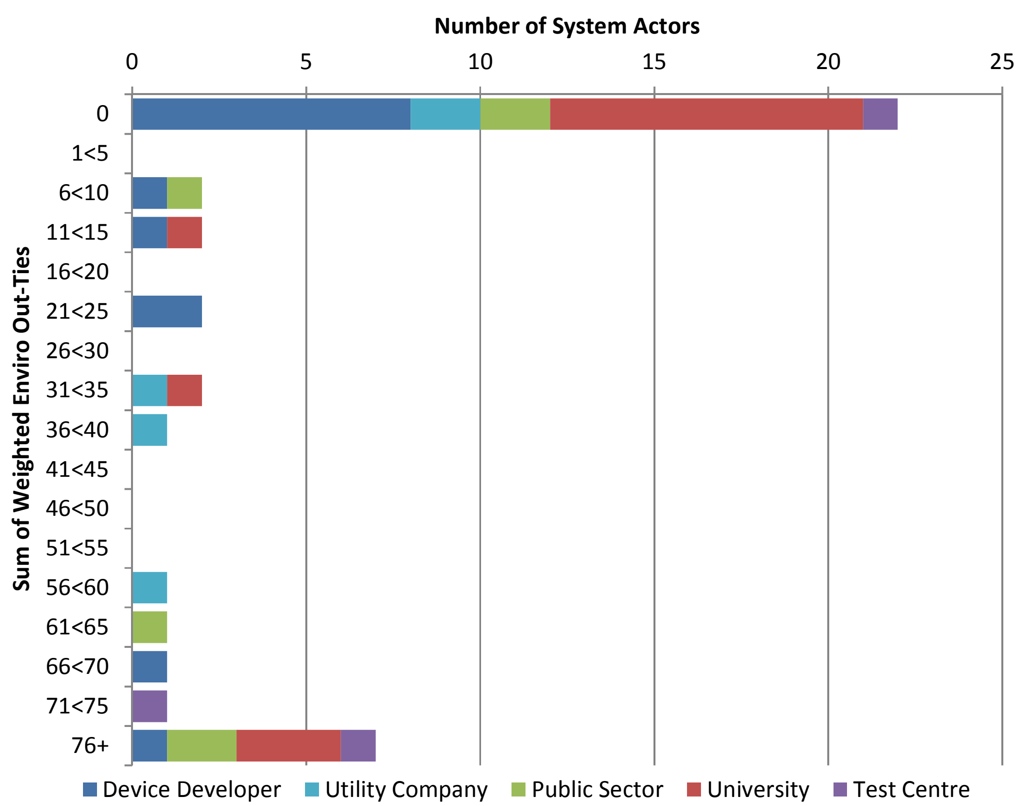
Technically, universities dominate heavily accounting for all but one of the central actors. The University of Edinburgh is clearly considered the highest contributor of technical knowledge to the sector (with around 30% higher centrality measures than the next highest, the University of Manchester). NAREC is also on the technical centrality table which, given its role as intermediary test centre between small scale testing and more advanced development, might be expected.

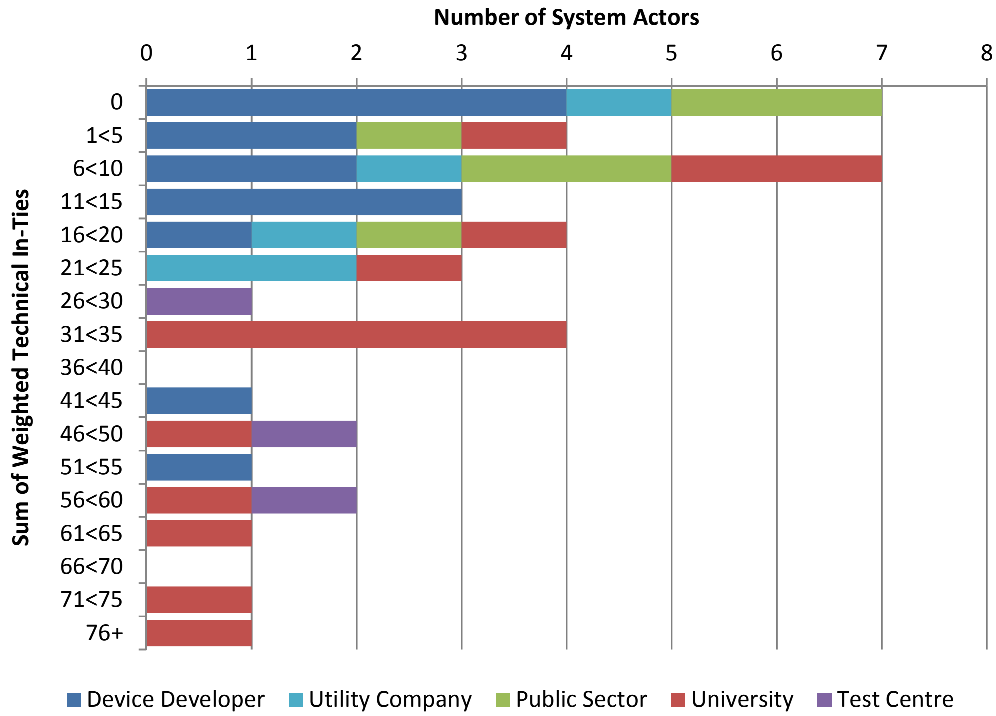
Within the market/fiscal networks, government and QUANGO agencies are dominant as the main fiscal support bodies for the sector. DECC and the Carbon Trust with the Scottish specific supporting bodies following closely behind provide the highest market/fiscal knowledge. Industrial representations again manages to make the bottom of the table with two trade associations at the bottom of the simple market centrality measure and the only device developer (Aquamarine Power) managing to make the bottom of the weighted centrality measure.

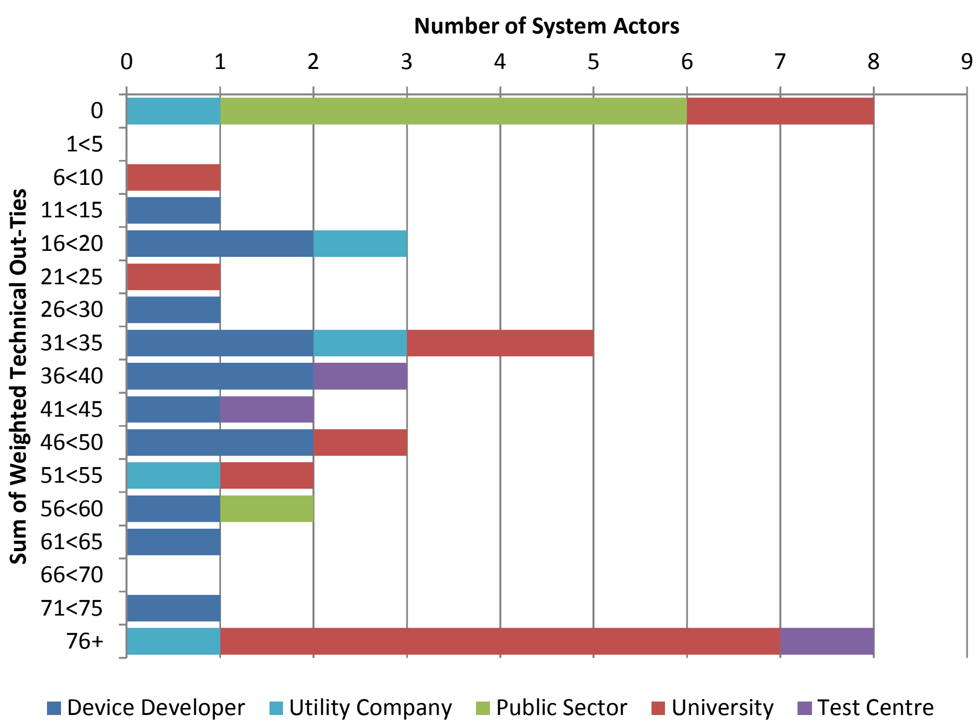
From the overall measures of diffusion reported by interviewees, 29 out of the 33 highest positions measured were ‘system actors’ within the study, comprising 19 actors out of a total of 23 referenced totally. The only non-system exceptions were Scottish Enterprise (3rd within both market centrality measures), the two environmental consultancy companies; Aquatera and Xodus Aurora (joint 5th in the non-weighted environmental table) and the Scottish Renewables industry network (joint 4th on the non-weighted market table).

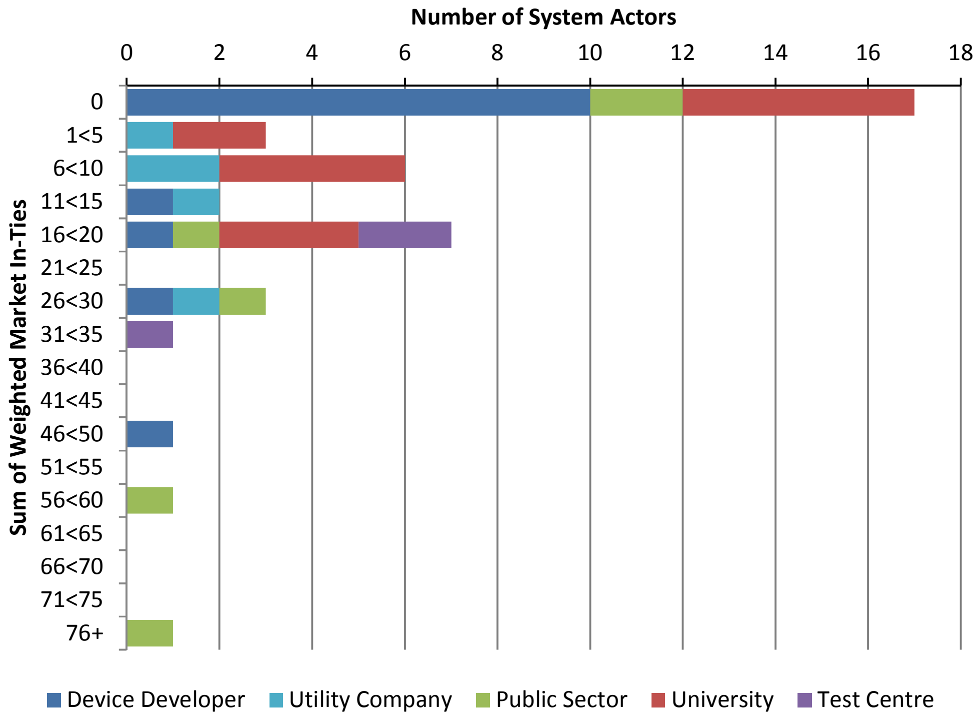
Histograms for the different weighted averages of system actors are shown in Figure 90 below:


Number of System Actors
0
2
4
6
8
10
12
14
16
Sum of Weighted Enviro. In-Ties
0
1<5
6<10
11<15
16<20
21<25
26<30
31<35
36<40
41<45
46<50
51<55
56<60
61<65
66<70
71<75
76+
Device Developer
Utility Company
Public Sector
University
Test Centre


Number of System Actors
0
5
10
15
20
25
Sum of Weighted Enviro Out-Ties
0
1<5
6<10
11<15
16<20
21<25
26<30
31<35
36<40
41<45
46<50
51<55
56<60
61<65
66<70
71<75
76+
Device Developer
Utility Company
Public Sector
University
Test Centre


Number of System Actors
0
1
2
3
4
5
6
7
8
Sum of Weighted Technical In-Ties
0
1<5
6<10
11<15
16<20
21<25
26<30
31<35
36<40
41<45
46<50
51<55
56<60
61<65
66<70
71<75
76+
Device Developer
Utility Company
Public Sector
University
Test Centre


Number of System Actors
0
1
2
3
4
5
6
7
8
9
Sum of Weighted Technical Out-Ties
0
1<5
6<10
11<15
16<20
21<25
26<30
31<35
36<40
41<45
46<50
51<55
56<60
61<65
66<70
71<75
76+
Device Developer
Utility Company
Public Sector
University
Test Centre



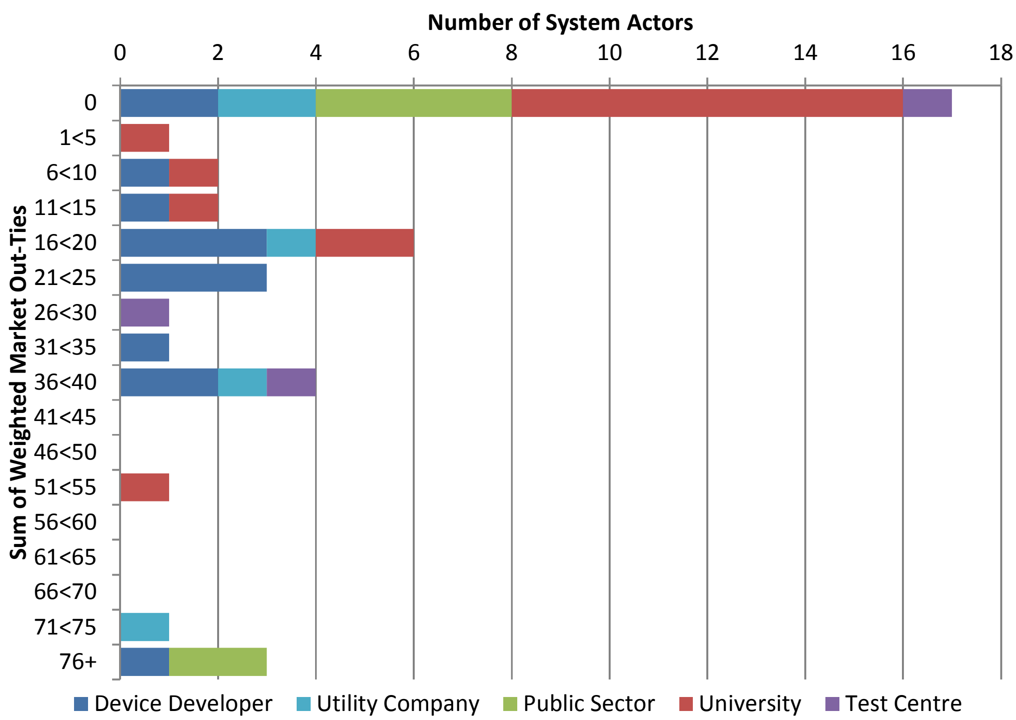


Figure 90: Measure of Weighted Centrality Histograms

7.3.1b Individual Stakeholder Network Contributions

The above measures of centrality allow for an assessment of the individual and absolute level of contribution that an actor provides. The betweenness-flow centrality and the standard harmonic closeness centrality measure however provides for a valuation of the overall network contribution beyond a simple reading of contribution towards one's 'alters' (See SNA measures within the literature review for more details).

Individual Stakeholder Harmonic Closeness Centrality of Actors

As this analysis can only be performed upon non-valued data, (i.e. it does not count the value strength of the tie) the data set must be dichotomised at a point in which, below this value, there is considered to be no exchange and above this value there is considered to be 'full exchange'. This is unfortunately an arbitrary measure however when assessing the affects of dichotomisation, the change in both network density and overall number of ties as a result of dichotomisation are strong indicators as to the effect upon network topology and impact. As can be seen in Figure 91 below, although the technical network is effected to some extent (around 25% density change or 0.1% of absolute network density), a dichotomisation level of 3 will have a relatively low effect upon the sum network density and will thus result in a 'good fit' binary network to the original valued network without losing too much data or being overly inclusive within the dichotomisation.

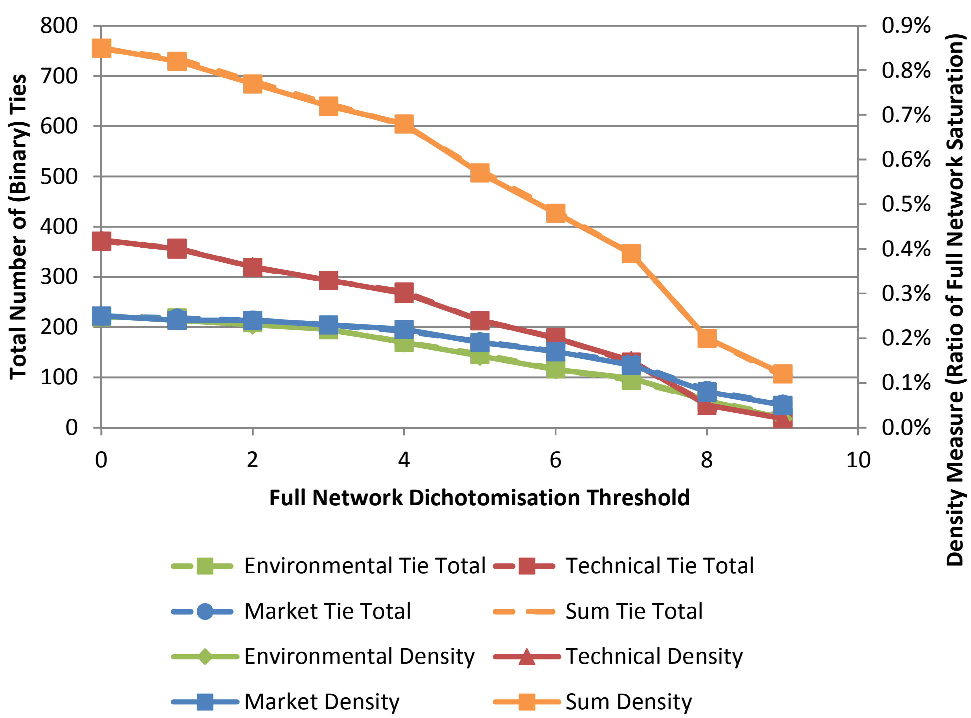


Figure 91: Full Network Density Measures for Varying Levels of Dichotomisation with the UK Wave Energy Sector

Taking a dichotomised value of 3, the resulting harmonic closeness measures that are calculated for all three networks as well as the summated network (i.e. the product of all three matrixes) as shown in Table 58 below:

Rank	Actor	Tech. Norm. Closeness	Market Norm. Closeness	Enviro. Norm. Closeness	Sum. Norm. Closeness	Adv. Tax
Highest Technical Normalised In Closeness						
1st	University of Edinburgh	7.33	2.57	2.80	9.17	30
2nd	University of Manchester	6.40	0.00	2.80	7.83	30
3rd	University of Strathclyde	6.32	2.49	2.80	7.89	30
4th	HMRC UCC	5.98	2.13	3.19	7.89	30
5th	EMEC	5.84	2.91	4.53	8.50	33
Highest Market Normalised In Closeness						
1st	DECC	4.84	4.42	4.03	8.61	24
2nd	Carbon Trust	5.59	4.33	2.80	8.67	28
3rd	Scottish Enterprise	3.04	4.31	3.13	7.41	24
4th	Scottish Government	4.50	3.47	3.24	7.52	24
5th	Technology Strategy Board	0.00	3.41	0.00	6.63	34
Highest Environmental Normalised In Closeness						
1st	Crown Estates	3.87	2.91	4.70	8.08	25
2nd	EMEC	5.84	2.91	4.53	8.50	33
3rd	Marine Scotland	3.79	1.94	4.36	7.35	24
4th	DECC	4.84	4.42	4.03	8.61	24
5th	Scottish Natural Heritage	0.00	0.00	3.86	6.60	25
Highest Summated Normalised In Closeness						
1st	University of Edinburgh	7.33	2.57	2.80	9.17	30
2nd	Carbon Trust	5.59	4.33	2.80	8.67	28
3rd	DECC	4.84	4.42	4.03	8.61	24
4th	Aquamarine Power	5.68	3.30	3.47	8.61	1
5th	EMEC	5.84	2.91	4.53	8.50	33

Table 58: Highest Harmonic In-Degrees Measures Within the Wave Energy Sector

This table shows a wide array of data on the makeup of the sector. For example, it can be seen that universities still heavily dominate the technical and engineering collaborative work being conducted. This is also the most cohesive knowledge field, with higher overall levels of harmonic closeness than any other network. Unsurprisingly, the main funding bodies make up the entirety of the market and financing network. This reflection is not only an evident measure of their position but is almost aligned with the levels of support provided by each body, (i.e. with the TSB at the bottom, moving through the Scottish funding regimes to the Carbon Trust who have provided the MRPF and finally to DECC who have spent more than any other single body on the sector). With regards to the most contributory environmental actors, although this is the least cohesive field, the Crown Estate is a clear prime-mover with EMEC in close second, followed by the primary licensing or statutory consultees. Finally, on the summated harmonic closeness measure, there is an unexpected diversity of actors with Edinburgh as the primary agent within the sector (understandably given its heavily central role within the technical research community). The Carbon Trust top DECC to the second position, this is possibly a reflection on the fact that the Carbon Trust's work is more 'grass roots' then DECC's (in terms of the level of technical maturity that they interact with) and despite their lack of involvement within the environmental field (having a collective weighted environmental in-degree score of only 9), they are highly active in resolving both technical and fiscal problems within the sector (with the technical field being more cohesive and then providing a higher weighting of centrality).

Other observations that can be made about the highest knowledge diffusing actors within the different knowledge fields includes the lack of presence for both the Marine Management Organisation (MMO) as well as the Wave Hub test site within the environmental and planning categories. Additionally, there are no utility companies within the market and fiscal rankings or device developers within the technical/knowledge network. The first two of these network absences can be related to the level of establishment of both the MMO and Wave Hub. As (or if) these institutions begin to play a more centralised role, it would be expected that their level of network centrality would increase. Likewise, as the sector itself matures, it would be expected that financing would come more predominantly from the private sector (such as utility companies) and so these may become more central to the market/fiscal networks. With regards to the technical networks however, the most probable reasons for why device developers do not appear upon with the top of the network is twofold: Firstly, the *type* of technical of knowledge which they generate would more likely be *applied* technical knowledge and therefore both commercially sensitive, (and thus less reported) and by definition more likely to be carried out in-house. That is to say, systems integration is likely to be done in-house to the device developer whereas technical work on the creation of 'standards and protocols' are more likely to be done in a collaborative and open fashion. Secondly, much of the technical work carried out by device developers would be carried out in collaboration with their sub-component developers who were not considered to be part of the primary system analysis, (i.e. there are likely to be many component manufacturers who would report back that they have high levels of technical collaboration with mature device developers).

Individual Stakeholder Betweenness (Flow) Centrality of Actors

Based on Freeman's measure of betweenness (see Betweenness Centrality within the literature review or (Freeman *et al.*, 1991)), the measure of how contributory an actor is to the overall network in terms of knowledge flow can be measured. This measure does make the (erroneous) assumption that actors have full network rationality, (i.e. they will acquire information through whatever paths of communication are available) but does still provide a strong bias for 'whole-network' central actors without having to lose data detail through dichotomisation. Since the data has been coded as providing the *source* of information however (rather than the *flow* of information) the matrices require transposing before analysis to ensure that the outputs refer to those who provide knowledge rather than those who receive it. Results of the betweenness flow analysis are shown in Table 59 below:

Rank	Actor	Tech. Norm. Between-ness	Market Norm. Between-ness	Enviro. Norm. Between-ness	Sum. Norm. Between-ness	Adv. Tax
Highest Technical In Flow Betweeness						
1st	Aquamarine Power	4.87	1.65	1.82	10.91	1
2nd	Pelamis Wave Power Ltd	2.73	0.09	1.22	6.67	1
3rd	University of Edinburgh	1.69	0.05	0.02	1.54	30
4th	narec	0.66	0.00	0.00	0.55	33
5th	University of Manchester	0.61	0.00	0.00	0.91	30
Highest Market In Flow Betweeness						
1st	Aquamarine Power	4.87	1.65	1.82	10.91	1
2nd	Renewable UK	0.16	1.64	0.43	3.04	35
3rd	Scottish & Southern En.	0.03	1.55	0.01	0.04	17
4th	Scottish Government	0.00	0.57	0.01	0.18	24
5th	Marine Scotland	0.17	0.34	0.70	0.66	24

Highest Environmental In Flow Betweeness						
1st	Aquamarine Power	4.87	1.65	1.82	10.91	1
2nd	Pelamis Wave Power Ltd	2.73	0.09	1.22	6.67	1
3rd	Scottish Natural Heritage	0.00	0.00	1.18	0.36	25
4th	Uni. of the H.&I.	0.00	0.00	1.15	0.16	30
5th	Marine Scotland	0.17	0.34	0.70	0.66	
Highest Summated In Flow Betweeness						
1st	Aquamarine Power	4.87	1.65	1.82	10.91	1
2nd	Pelamis Wave Power Ltd	2.73	0.09	1.22	6.67	1
3rd	Renewable UK	0.16	1.64	0.43	3.04	35
4th	University of Edinburgh	1.69	0.05	0.02	1.54	30
5th	University of Manchester	0.61	0.00	0.00	0.91	30

Table 59: Highest Betweenness In Flow Measures Within the Wave Energy Sector

Interestingly Table 59 suggests the two device developer companies, Aquamarine Power and Pelamis Wave Power both score very highly on the flow betweeness. This is possibly because, as device developers they need to have a high level of interaction with a wide and heterogeneous number of stakeholders at all levels of both technology development and deployment encompassing almost all of the primary stakeholder types. Unlike these actors, many stakeholders, (universities for example) have no immediate requirement to interact with (for example) device developers, test centres or public sector bodies. Additionally, most device developers are themselves referenced by most central actors, (i.e. the most influential universities and government bodies). Aside from these two device developers, centrality rankings are similar to those of the weighted, non-weighted and (to a lesser degree) harmonic closeness scores.

7.3.1c Individual Stakeholder Cohesion Density/ Average Tie Scores

Measures of density for the valued network calculate the average overall weighting for each tie however this would give a misleadingly low value if conducted upon this asymmetric network since not all members of the system were interviewed and therefore all 'pendent' nodes (i.e. non-system actors) would reduce the overall level of density which, given the high levels of interaction with non-system actors, would provide much less insightful feedback.

To overcome this problem, the data was transformed into a reciprocal data set, (i.e. all weighted ties were assumed equal in both direction) *for non-interviewed actors only* (i.e. non system actors and non-respondent actors). For dyadic relationships where reciprocity already exists, (i.e. where interviewed system actors have referenced each other) the mean average weighting of the relationship within each knowledge field was assumed. The matrices were also transposed to show lines of direct knowledge flow (rather than whom stakeholders acquire knowledge from).

For the summated network, reciprocity was assumed on all knowledge fields *if it was present within one knowledge field* (i.e. a reciprocity value of 0 was assumed on any non-referenced knowledge fields between any two actors who referenced each other within any other knowledge field). The reason for this was threefold: Firstly, it assumed that any actor who referenced another actor in *any* knowledge field would also think to cover other knowledge fields that they interact upon (rather than remembering that there is an interaction but forgetting the full make-up of the interaction); secondly, it allowed for differing types of interaction between stakeholders (i.e. a utility company may provide a financial/market relationship to an environmental consultant who in return provides an environmental/planning interaction back); finally, it prevented unrealistically high levels of density between actors by normalising their collective relationship (i.e. if they did forgot to mention a relationship with a noted alter stakeholder, it would be reasonable to assume it was less valuable to them than it was to the alter stakeholder).

For example, this would mean that if an actor reported an intensity of 10 on all three knowledge fields with an alter system actor and this alter recorded 5 on just one field in return, their overall level of reciprocal summated interaction would be coded as 17.5, (((10+5)/2) +((10+0)/2)+((10+0)/2)=7.5+5+5=17.5).

Individual Stakeholder Density Measures of Actors by Nation

National density scores for the five highest summated network density actors (i.e. those most influential to the nation's wave energy sector knowledge generation) are shown for England and Scotland in Table 60 below

International, Welsh and Northern Ireland levels of cohesion density are removed since they are purely based upon reciprocity assumptions with interviewed actor and the data sets for Northern Ireland consists of only two interviewed actor (Queen's University Belfast and Pure

Marine Energy) as well as reciprocity with 3 other stakeholders and is thus not considered robust enough to make insightful conclusions.

				Total Summated Tie Strength From Nation					Summated Density From Nation				
		Company:	Nationality:	English	Scottish	Welsh	N. Ireland	International	English	Scottish	Welsh	N. Ireland	International
Top From England	1st	Renewable UK	Eng	462	178	20	15	104	3.08	2.91	5	3.00	1.33
Top From England	2nd	University of Edinburgh	Scot	146	98	0	21	258	0.96	1.63	0	4.20	3.30
Top From England	3rd	EMEC	Scot	127	207	0	1	61	0.84	3.45	0	0.20	0.78
Top From England	4th	Wave Hub	Eng	117	34	8	0	7	0.78	0.55	2	0.00	0.09
Top From England	5th	University of Exeter	Eng	116	21	0	3	40	0.77	0.34	0	0.60	0.51
Top From Scotland	1st	EMEC	Scot	127	207	0	1	61	0.84	3.45	0	0.20	0.78
Top From Scotland	2nd	Marine Scotland	Scot	99	200	0	0	26	0.65	3.33	0	0.00	0.33
Top From Scotland	3rd	Renewable UK	Eng	462	178	20	15	104	3.08	2.91	5	3.00	1.33
Top From Scotland	4th	Scottish Government	Scot	32	128	0	0	0	0.21	2.13	0	0.00	0.00
Top From Scotland	5th	Pelamis Wave Power Ltd	Scot	94	117	0	0	60	0.62	1.95	0	0.00	0.76

Table 60: Top five Most Cohesive National Actors with England and Scotland

One thing that is striking is the strong presence of RenewableUK in both top 5 lists. This is as a result of the large network of non-system actors that were referenced by RenewableUK within the interview process which (as a result of reciprocity weighting for non-system actors) has led to RenewableUK ranking first within the English table and 3rd within the Scottish. Even with this irregularity, an interesting feature of the table is that the 2nd and 3rd 'densest' actors within the English network are based in Scotland (University of Edinburgh and EMEC) as well as four of the top five within Scotland (with RenewableUK being the only exception). This table therefore clearly shows that Scottish actors are not only more contributory to English networks then most English actors but also that the overall density levels of cohesion within the top actors in Scotland are around three times higher than the top English actors (i.e. between 1.95<3.45 for Scotland as opposed to 0.773<0.967 for Scotland exclusive of RenewableUK).

Individual Stakeholder Density Measures of Actors by Stakeholder Type

As with the national cohesion analysis, stakeholder type cohesion shows the five most cohesive (highest density) contributors to the different stakeholder groups. Within this analysis, the ‘Other Company’ type as well as the ‘Collaborative Affiliations’ stakeholder cohesion rankings are removed since these actors are outside of the system boundary of the study and thus, all metrics for these agents are based solely upon reciprocity between themselves and system actors who referenced them (with the exception of RenewableUK who were the only ‘collaborative affiliation’ to be interviewed as part of the primary research).

The results from the stakeholder type cohesion analysis are show in Table 61 and Table 62 below:

				Total Summated Tie Strength From Stakeholder Type							
			Stakeholder Type	Device Developer	Other Company	Utility Company	Central Gov. Dep	Other Dep	University	Test Centre	Coll. Aff.
D. Developer	1st	Carbon Trust	Other Dep	74	0	0	0	0	23	9	10
	2nd	Scottish Government	Cent. Gov	50	16	22	8	24	14	10	16
	3rd	DECC	Cent. Gov	48	0	18	20	8	19	25	10
	4th	Marine Scotland	Cent. Gov	42	5	19	67	80	11	10	91
	5th	Uni. of Edinburgh	University	40	96	28	45	39	224	17	34
Utility Comp	1st	EMEC	Test Centre	38	66	50	34	69	100	0	39
	2nd	Crown Estates	Other Dep	28	0	42	26	4	3	18	10
	3rd	Renewable UK	Coll. Aff.	39	200	31	92	162	93	11	151
	4th	Uni. of Edinburgh	University	40	96	28	45	39	224	17	34
	5th	Pelamis WP.	Developer	0	97	22	36	37	39	10	30
Cent. Gov	1st	Renewable UK	Coll. Aff.	39	200	31	92	162	93	11	151
	2nd	Marine Scotland	Cent. Gov	42	5	19	67	80	11	10	91
	3rd	Uni. of Edinburgh	University	40	96	28	45	39	224	17	34
	4th	Aquamarine Power	Developer	0	24	22	44	22	42	20	9
	5th	Highlands & Isl. Enterprise	Other Dep	0	0	6	38	0	24	10	0
Other Dep	1st	Renewable UK	Coll. Aff.	39	200	31	92	162	93	11	151
	2nd	Marine Scotland	Cent. Gov	42	5	19	67	80	11	10	91
	3rd	EMEC	Test Centre	38	66	50	34	69	100	0	39
	4th	Uni. of Edinburgh	University	40	96	28	45	39	224	17	34
	5th	Pelamis WP.	Developer	0	97	22	36	37	39	10	30
University	1st	Uni. of Edinburgh	University	40	96	28	45	39	224	17	34
	2nd	EMEC	Test Centre	38	66	50	34	69	100	0	39
	3rd	Renewable UK	Coll. Aff.	39	200	31	92	162	93	11	151
	4th	Uni. of Plymouth	University	20	46	2	0	9	83	8	8
	5th	Heriot Watt Uni. ICIT	University	18	15	2	4	18	70	6	20
Test Centre	1st	DECC	Cent. Gov	48	0	18	20	8	19	25	10
	2nd	Aquamarine Power	Developer	0	24	22	44	22	42	20	9
	3rd	Ocean Power Technologies	Developer	0	26	4	18	23	10	18	9
	4th	Crown Estates	Other Dep	28	0	42	26	4	3	18	10
	5th	Uni. of Edinburgh	University	40	96	28	45	39	224	17	34

Table 61: Top five most Cohesive Actors within the Different Stakeholder Types (Summated Influence Value)

				Total Summated Group Density From Stakeholder Type							
			Type	Device Developer	Other Company	Utility Company	Central Gov. Dep	Other Dep	University	Test Centre	Coll. Aff.
Developer	1st	Carbon Trust	Other Dep	3.22	0.00	0.00	0.00	0.00	0.34	3.00	0.26
	2nd	Scottish Government	Cent. Gov	2.17	0.15	2.44	0.73	0.60	0.21	3.33	0.42
	3rd	DECC	Cent. Gov	2.09	0.00	2.00	1.82	0.20	0.28	8.33	0.26
	4th	Marine Scotland	Cent. Gov	1.83	0.05	2.11	6.09	2.00	0.16	3.33	2.39
	5th	Uni. of Edinburgh	University	1.74	0.90	3.11	3.75	0.98	3.39	5.67	0.89
Utility Comp	1st	EMEC	Test Centre	1.65	0.62	5.56	2.83	1.73	1.49	0.00	1.03
	2nd	Crown Estates	Other Dep	1.22	0.00	4.67	2.17	0.10	0.04	6.00	0.26
	3rd	Renewable UK	Coll. Aff.	1.70	1.87	3.44	7.67	4.05	1.39	3.67	4.08
	4th	Uni. of Edinburgh	University	1.74	0.90	3.11	3.75	0.98	3.39	5.67	0.89
	5th	Pelamis WP.	Developer	0.00	0.91	2.44	3.00	0.93	0.58	3.33	0.79
Cent. Gov	1st	Renewable UK	Coll. Aff.	1.70	1.87	3.44	7.67	4.05	1.39	3.67	4.08
	2nd	Marine Scotland	Cent. Gov	1.83	0.05	2.11	6.09	2.00	0.16	3.33	2.39
	3rd	Uni. of Edinburgh	University	1.74	0.90	3.11	3.75	0.98	3.39	5.67	0.89
	4th	Aquamarine Power	Developer	0.00	0.22	2.44	3.67	0.55	0.63	6.67	0.24
	5th	Highlands & Isl. Enterprise	Other Dep	0.00	0.00	0.67	3.17	0.00	0.36	3.33	0.00
Other Dep	1st	Renewable UK	Coll. Aff.	1.70	1.87	3.44	7.67	4.05	1.39	3.67	4.08
	2nd	Marine Scotland	Cent. Gov	1.83	0.05	2.11	6.09	2.00	0.16	3.33	2.39
	3rd	EMEC	Test Centre	1.65	0.62	5.56	2.83	1.73	1.49	0.00	1.03
	4th	Uni. of Edinburgh	University	1.74	0.90	3.11	3.75	0.98	3.39	5.67	0.89
	5th	Pelamis WP.	Developer	0.00	0.91	2.44	3.00	0.93	0.58	3.33	0.79
University	1st	Uni. of Edinburgh	University	1.74	0.90	3.11	3.75	0.98	3.39	5.67	0.89
	2nd	EMEC	Test Centre	1.65	0.62	5.56	2.83	1.73	1.49	0.00	1.03
	3rd	Renewable UK	Coll. Aff.	1.70	1.87	3.44	7.67	4.05	1.39	3.67	4.08
	4th	Uni. of Plymouth	University	0.87	0.43	0.22	0.00	0.22	1.26	2.67	0.21
	5th	Heriot Watt Uni. ICIT	University	0.78	0.14	0.22	0.33	0.45	1.06	2.00	0.53
Test Centre	1st	DECC	Cent. Gov	2.09	0.00	2.00	1.82	0.20	0.28	8.33	0.26
	2nd	Aquamarine Power	Developer	0.00	0.22	2.44	3.67	0.55	0.63	6.67	0.24
	3rd	Ocean Power Technologies	Developer	0.00	0.24	0.44	1.50	0.57	0.15	6.00	0.24
	4th	Crown Estates	Other Dep	1.22	0.00	4.67	2.17	0.10	0.04	6.00	0.26
	5th	Uni. of Edinburgh	University	1.74	0.90	3.11	3.75	0.98	3.39	5.67	0.89

Table 62: Top five most Cohesive Actors within the Different Stakeholder Types (Density Measures)

7.3.2 Sub Group Knowledge Generation and Diffusion

Sub group analysis can be conducted between various groups within the network to assess the levels of; cross-group interactions (through 'supernode' analysis), group centralities (through group centrality measures) and group cohesion, (through group cohesion measures) that are occurring. Through application of these measures, validation of various primary questions within the network (such as, 'does Scotland have a more cohesive network of interaction then England or are there high levels of interaction between device developers and universities?) can be made. Group centrality measures are only calculated for binary relationships between actors thus, (as with the harmonic closeness measures used within section 7.3.1b) a dichotomisation level of 3 was applied to the different networks. This means that any actor pair with a directed relationship of 3 will be considered to have a (directed and binary) relationship.

This sub group analysis will cover the following groups of actors:

- Different Countries: Specifically, Scotland, England and internationally to assess the overall flows between these nationalities.
- Different Actor Types: Universities, device developers, test centres and public sector bodies to assess who the most cohesive actor types are and how much interaction between these groups there is.
- Different identified formal networks: Such as EQUIMAR, SUPERGEN and those networks identified within the Market Formation section (6.7.1) of Chapter 6, Established Measures.

(NOTE: Networks that include other networks, such as SUPERGEN being a member of MREDS, have been removed from the analysis for clarity).

For ease of interpretation the analysis has been done by grouping type (i.e. nationality etc.) rather than knowledge flow type. Normalised scores have not been included since they would give a misleading impression of centrality (since only 43 actors were involved in the network of 299 and thus normalised scores would be misleadingly low).

Interpreting the differences between the supernode analysis and the group centrality measures needs a basic understanding of the evaluation methods. The group centrality measure is effectively a measure of the number of external (to the group) individual stakeholder organisations that a group type is dealing with within that particular knowledge field (i.e. multiple relations to the same stakeholder from different members of a network will only be valued at one within each knowledge field). Therefore a group with a large group centrality score can be said to have a *wide* reach of influence in that it is involved with a high number of institutes however it does not relate to the overall intensity of interaction.

The supernode analysis however is a summated weighting score from each group type to each other group type providing an indication as to the systemic accumulated knowledge flows from group to group. A group with a high supernode influence score can therefore said to be providing a high level of interaction/knowledge flow to the wider community however it does not show how well distributed this interaction is other than between group types. Note also that the supernode analysis allows for internal knowledge feedback which is a measure of the amount of knowledge flow generated and received internally to that group type.

The findings for the levels of group centrality and the supernode analysis are shown in Figure 92 and Figure 93 (for Nationalities), Figure 94 and Figure 95 (for Actor Types) and Figure 96 (for Established Network types) below:

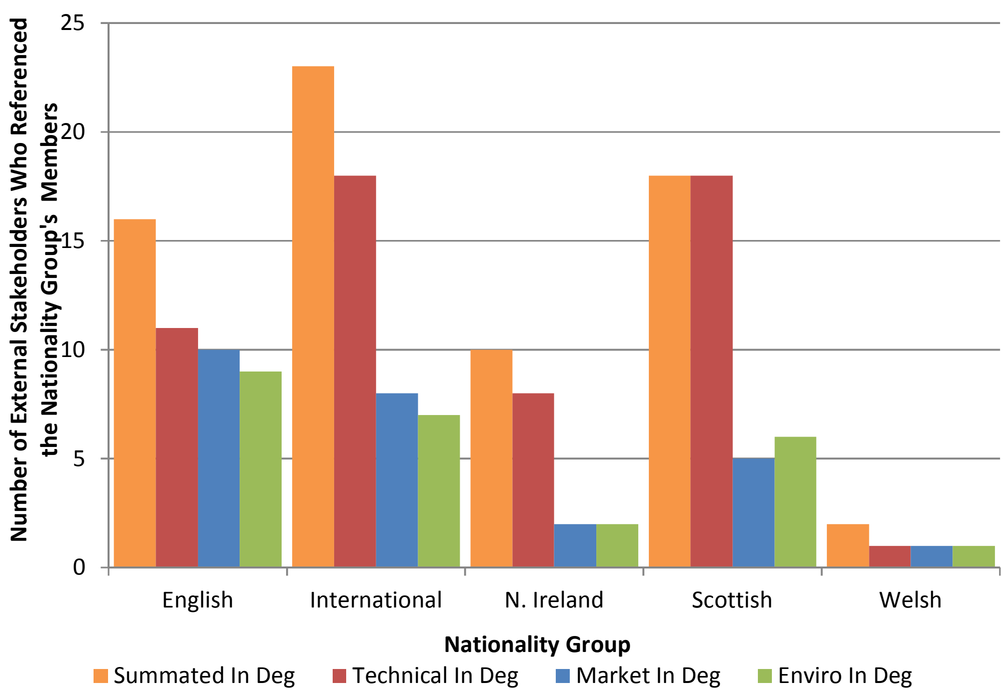


Figure 92: Group Centrality Measures for Different Nationalities

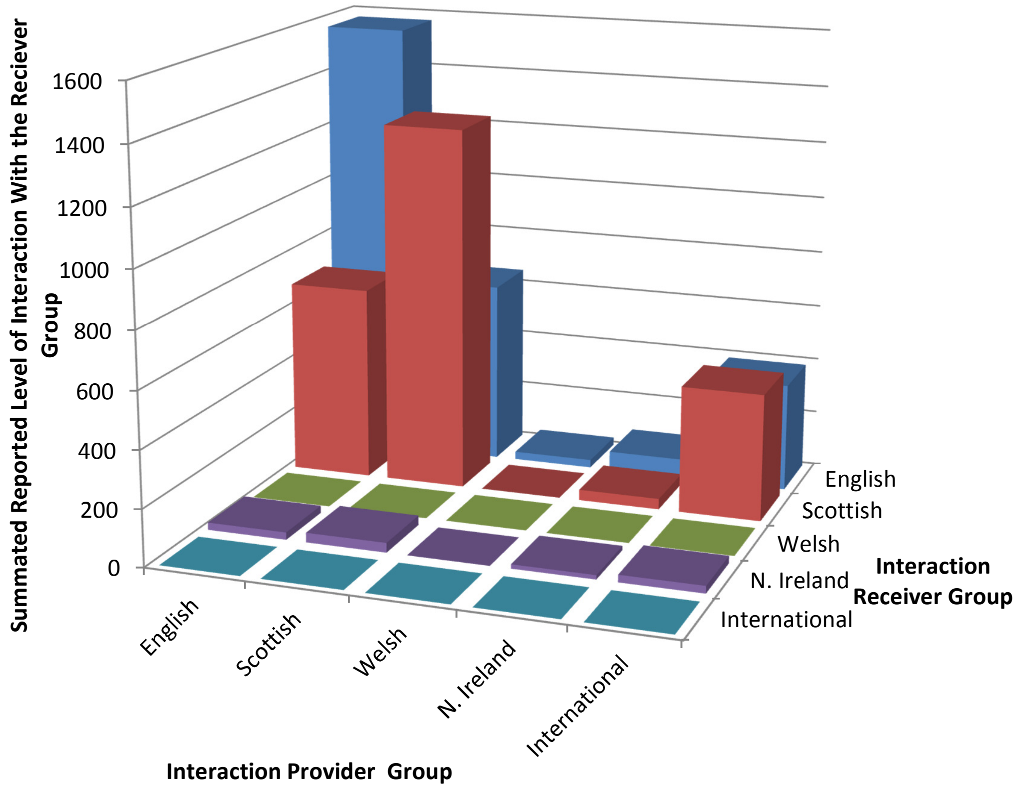


Figure 93: Supernode Centrality Analysis of Different Nationalities

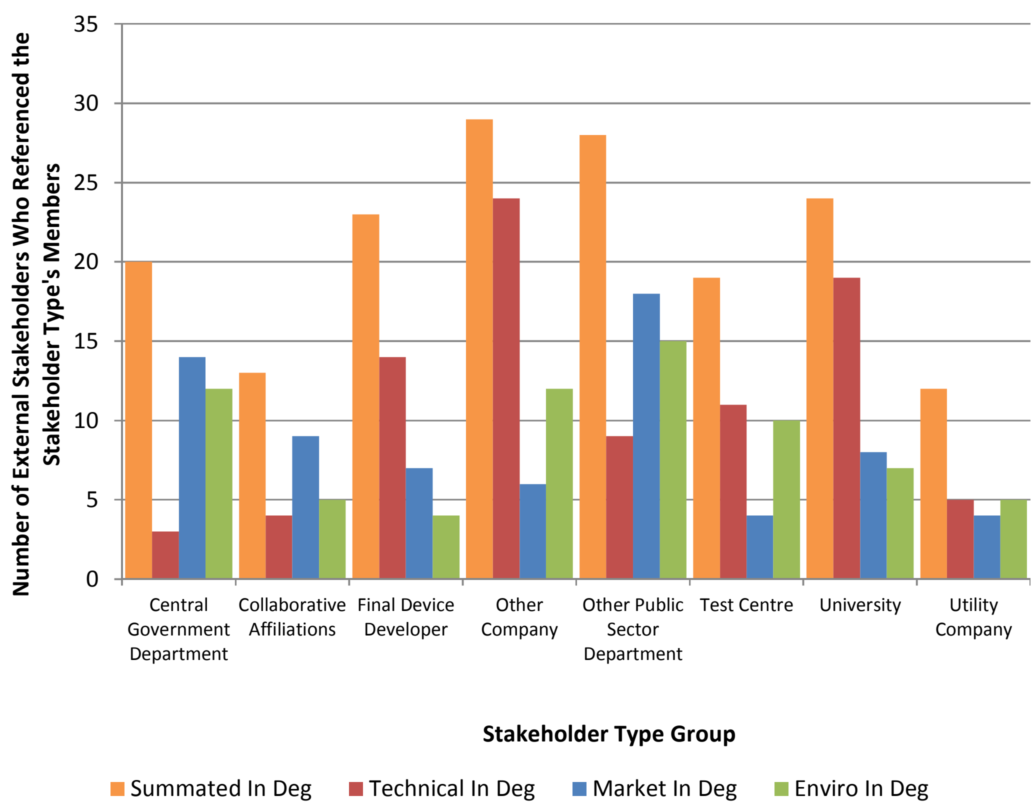


Figure 94: Group Centrality Measures for Different Stakeholder Types

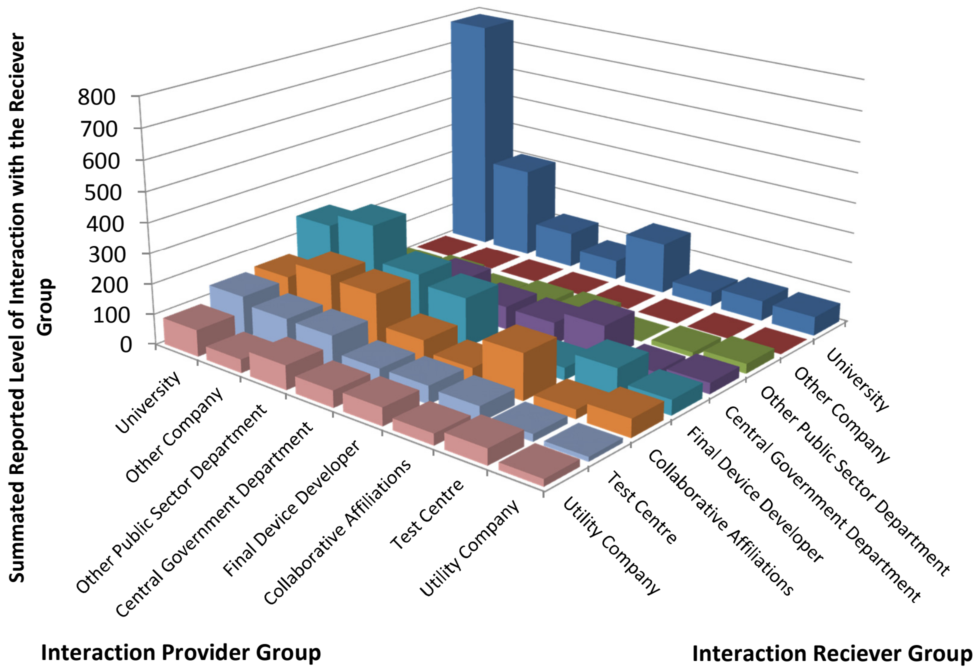


Figure 95: Supernode Centrality Analysis of Different Stakeholder Types

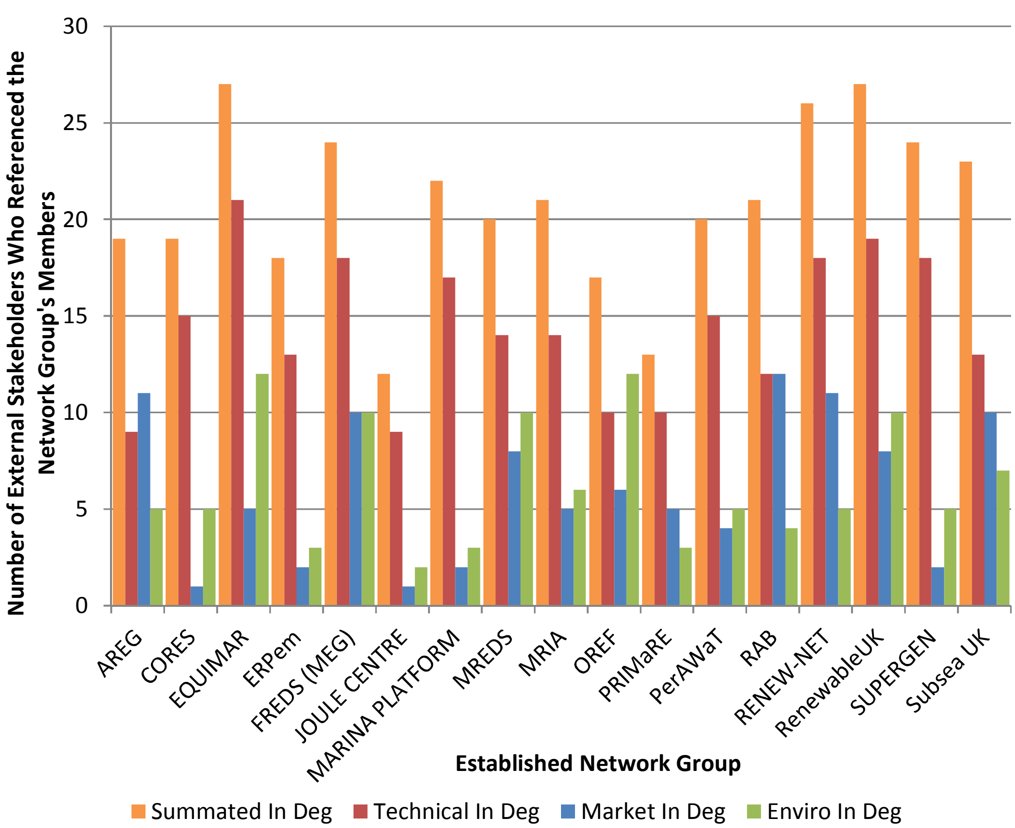


Figure 96: Group Centrality Measures for Different Established Networks

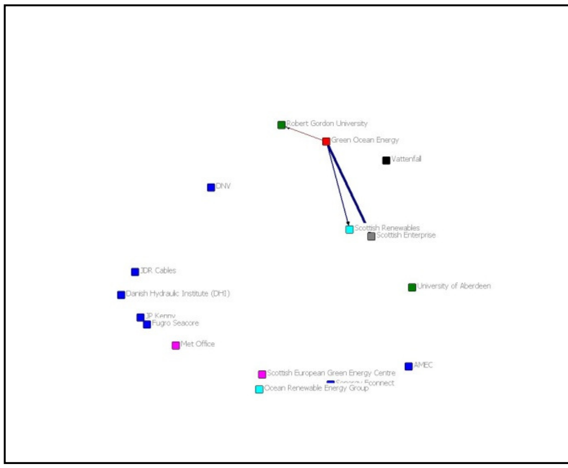
Established Networks as supernodes are not possible since many of the individual stakeholders are present within more than one established network and thus the level of inter-network communication would be somewhat misleading and redundant (see Market Formation section (6.7.1) of Chapter 6, Established Findings for more details on established networks).

Likewise, since the networks are themselves made up of many actors, not all of whom are part of the system boundary of the study, conducting sub-group analysis such as group density, group cluster coefficients etc would provide misleading results and thus the only strong measure that can be conducted is those above which themselves show what influence the established networks have had upon the system actors under analysis.

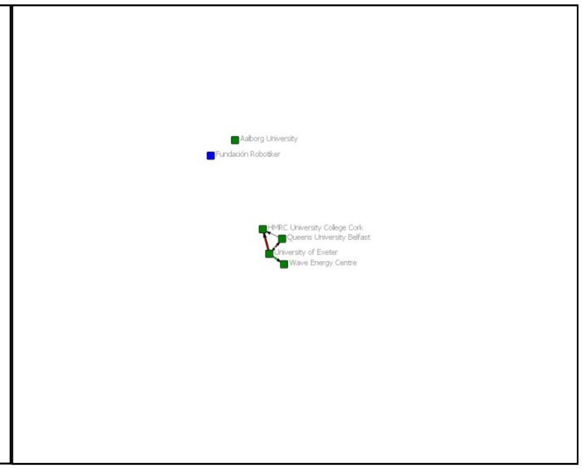
What can be done that provides some insight is to extract the network actors from the overall network and view this as a separate network to provide information on the following:

- The level and type of interactions reported by respondents (i.e. system actors) within the network.
- The multidimensional scaling locations for each network which positions actors within the overall network in a location relative to their number of shared ties. Actors with the highest number of shared ties will be situated closer to each other than those who share less or none. This reflects a measure of the homophile of actors within the network.
- Their absolute location within each diagram which shows their relative level of betweenness centrality to the overall network both individually and as a network.

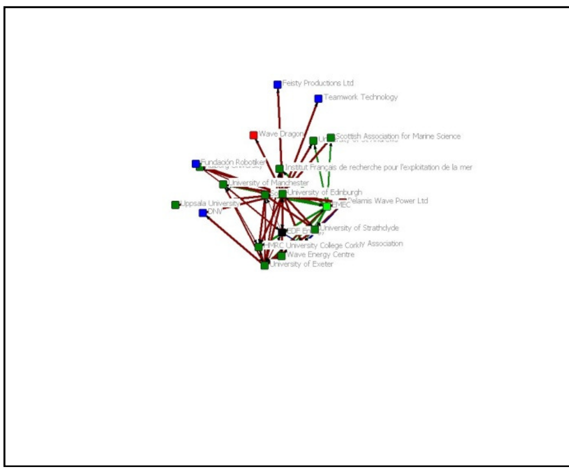
These diagrams for established networks can be seen below in the various slides of Figure 97 below:



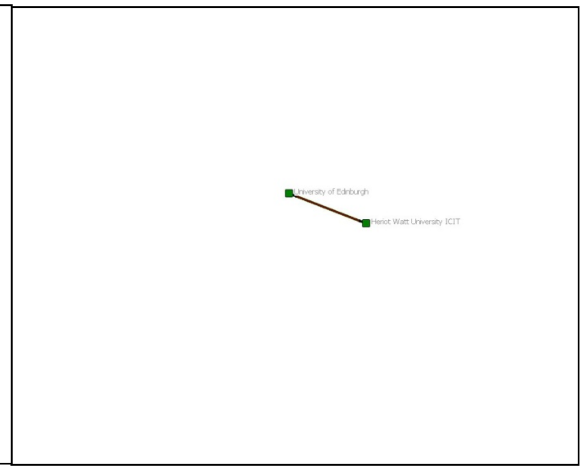
AREG



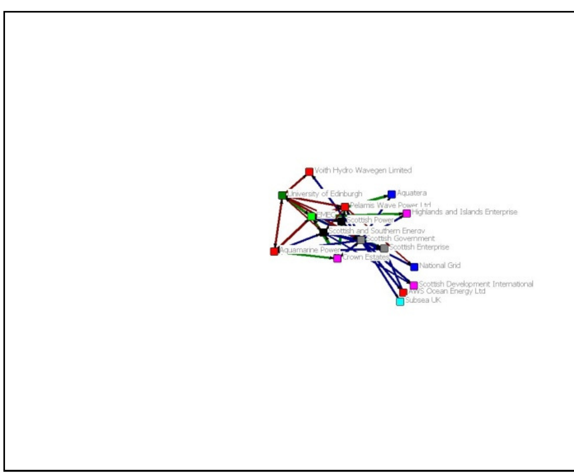
CORE



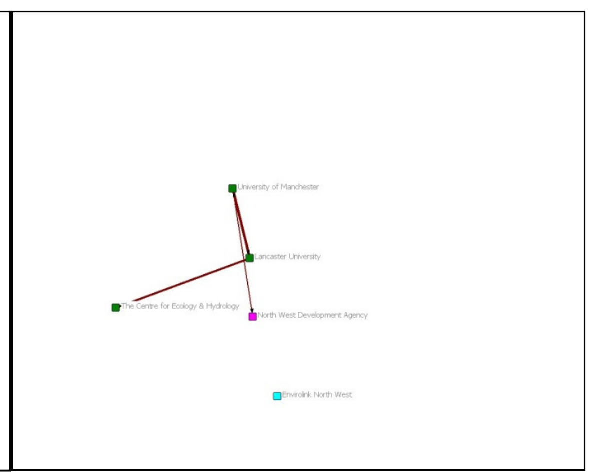
EQUIMAR



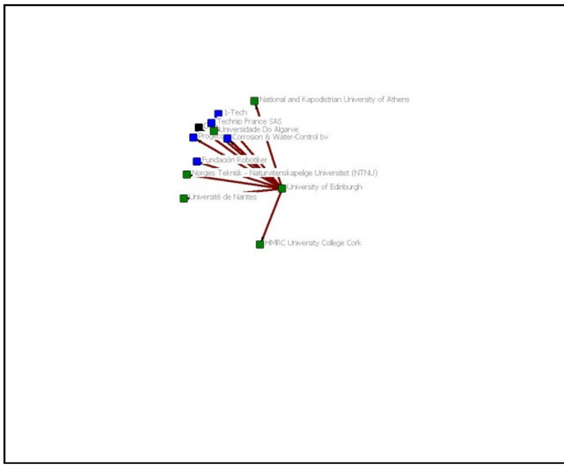
ERPem



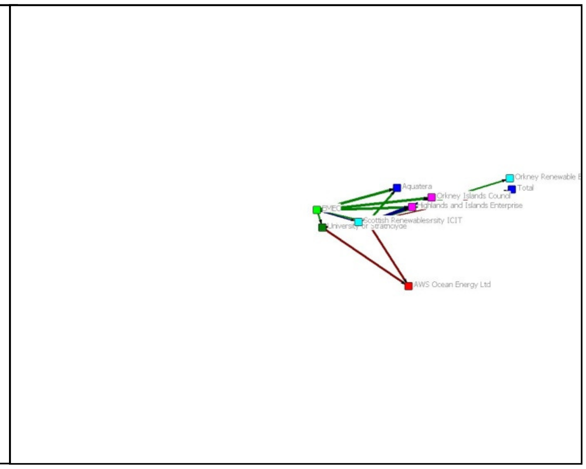
FREDS (MEG)



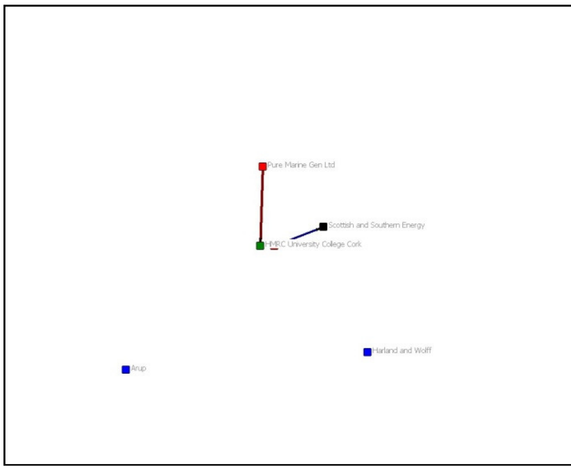
JOULE CENTRE



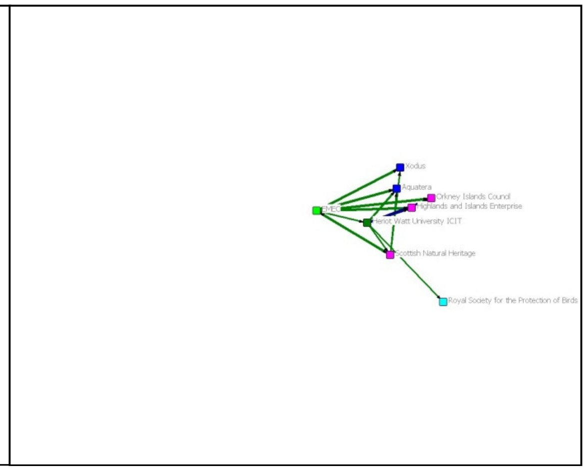
MARINA PLATFORM



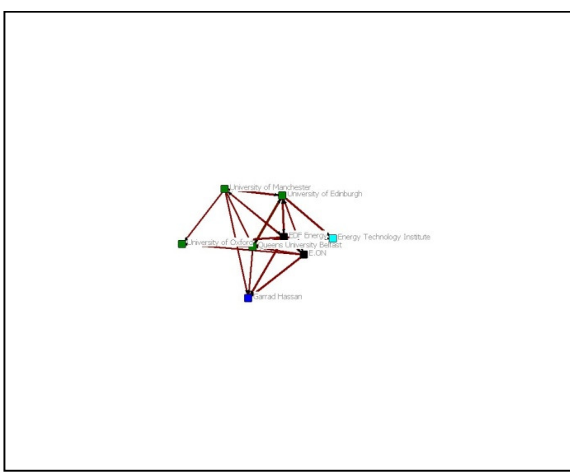
MREDS



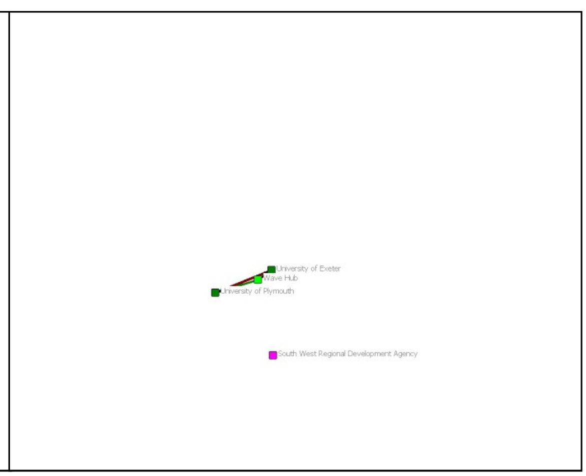
MRIA



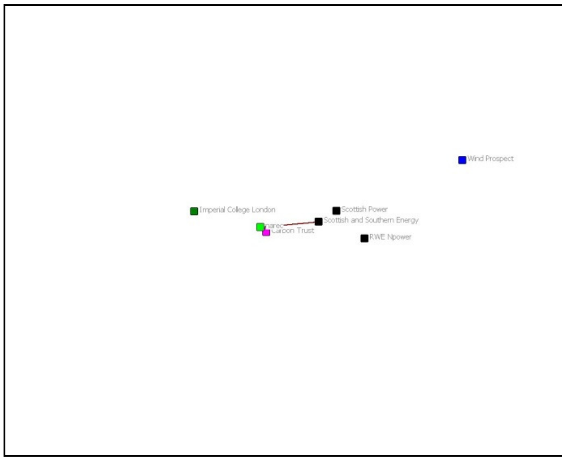
Orkney RE Forum



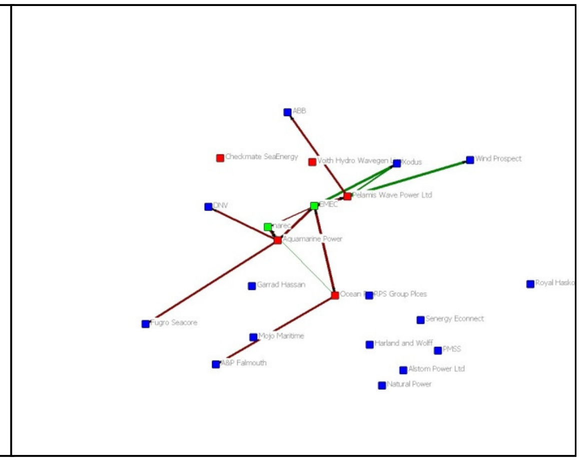
PERAWAT



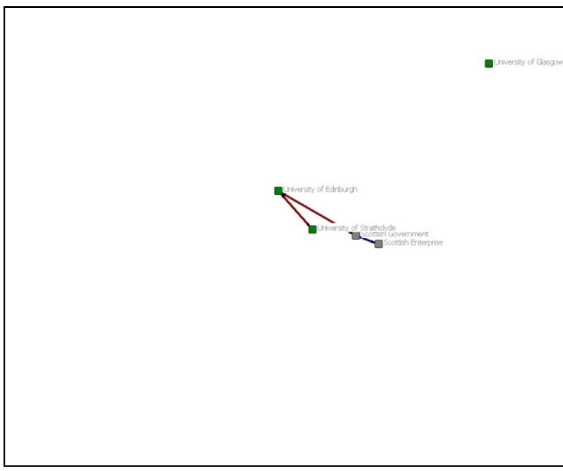
PRIMARE



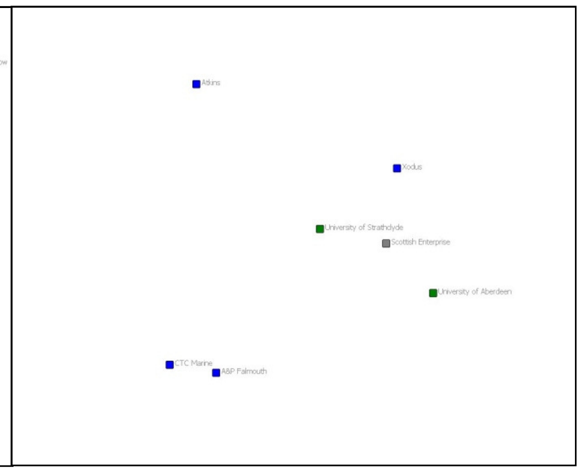
Renewable Advisory Board



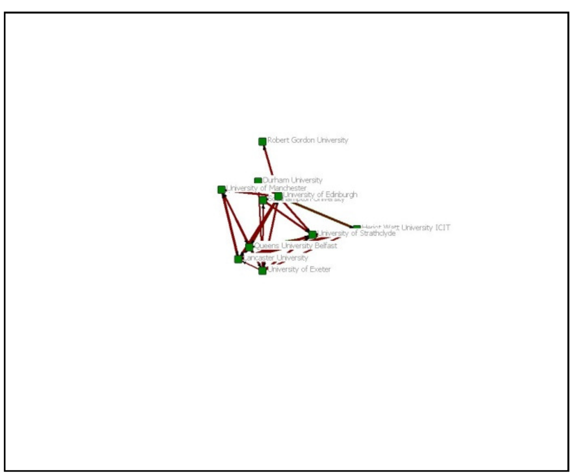
RenewableUK



Renew-NET



SubSea UK



SUPERGEN

	Final Device Developer
	Other Company
	Utility Company
	Central Government Department
	Other Public Sector Department
	University
	Test Centre
	Collaborative Affiliations

Figure 97: Established Networks

Although the above networks show only wave energy interactions within, between or towards system actors within the sector, it can clearly be seen that there are some very cohesive networks, (such as SUPERGEN and PERAWAT's technical collaboration networks and Orkney Renewable Energy Forum's environmental network) as well as far more dispersed and less internally collaborative networks (such as SubSea UK which although contains a mixture of network actors, has no interactive ties within the wave energy sector). Others are something of a mix such as RenewableUK or FREDS MEG which covers more than one relationship within their networks. As with all of these networks however, causality cannot be shown and therefore it cannot be surmised that this communication is as a result of, in response to or independent of the established network's presence.

7.3.3 Full Network Knowledge Generation and Diffusion

The full network was processed for average value scores as outlined within section 7.1.3 for individual actor cohesion metrics. Results for whole sector network density are shown in Table 63 and Table 64 below:

Full Valued (Reciprocal) Network Density	Avg Value	Std Dev
Technical Cohesion	0.0388	0.5212
Market Cohesion	0.0312	0.4973
Environmental Cohesion	0.0255	0.4327
Summated Cohesion	0.0955	0.9085

Table 63: Full Valued Wave Energy Sector Network Density Measures

Full Dichotomised (3) (Reciprocal Modified) Network Density	Density	No. of Ties
Technical Cohesion	0.0052	460
Market Cohesion	0.004	353
Environmental Cohesion	0.0034	307
Summated Cohesion	0.0117	1046

Table 64: Full Dichotomised Wave Energy Sector Network Density Measures

Interpreting the data, it can be seen that (as expected) the summated network is clearly the most cohesive network. Out of the remaining three knowledge fields however there seems to be a far higher (relative) level of technical cohesion as well as higher (but still extremely low) average tie strength. Following on from this, Market cohesion is slightly higher than environmental/planning cohesion. It is impossible to tell whether these levels of cohesion are low or high in absolute terms since there are no benchmarking levels to compare to however they can be compared both relatively to each other and as a baseline to the sub group cohesion analysis that is provided within section 7.1.3c above.

7.4 Market Formation

Since looking at the overall market formation within the network relates to the level of connectivity of its actors, the most apparent metric within SNA is that of density. Density is a measure of the level of connectivity saturation within the network as a fraction of the absolute network saturation within the network (i.e. assuming that everyone has maximum levels of communication with each other agent).

Although network density measures are useful for comparing relative network property (i.e. how alike two similar networks are) it is more ambiguous when taken alone as an indication of how 'innovative' the network is supposed to be. This is due to several factors. Firstly, it is unrealistic (or un-insightful) to imply that a continually higher level of network density is always going to provide a higher level of innovation given that maximum network saturation is neither likely to occur or indeed (given the nature of the network) even desirable (when taking into account transaction costs between agents and diminishing returns of connectivity). Secondly, since non-network actors are not involved within the interview process, there is no potential for maximum network saturation to occur as all relations recorded from non-system actors to system actors will always equal 0 (unless reciprocity is assumed).

Two metrics however that are less ambiguous are firstly; the level of network Inclusiveness within the system actor network which would show how many system actors are active within each specific knowledge field (Scott, 2009). Secondly, the average networks tie strength. This can be calculated based on both the system actor network *only* (i.e. removing 'pendent' non-system actors) and the full network inclusive of non-system actors. These metrics would show how much interaction is occurring on average between system actors within a knowledge field and how much is occurring as reported by system actors, (i.e. inclusive of non-system actors) respectively. These last two measures can be compared and it would be assumed that the value of intra-system-actor related communications (i.e. the first metric) would, on average - be higher than that of total (i.e. intra- and inter- system actor) relations. If this were not the case then system actors would collectively acquire most of their system knowledge from outside of the boundaries of the system.

7.4.1 Inclusiveness

The level of inclusiveness within the different knowledge fields as assessed from the data (i.e. the percentage of non-isolate network actors within the different knowledge fields) for system actors, the full network and non-system actors (i.e. the level of inclusiveness for non-system actors as referenced by system actors) is shown in Table 65 below:

	Environmental	Technical	Market	Summated
System Actors Only	61%	71%	58%	91%
The Full Network	38%	57%	39%	98%
Non-System Actors Only	32%	53%	35%	100%

Table 65: Inclusiveness of Different Knowledge Networks and Different System Actor Types

As can be seen, the technical network is substantially more inclusive than both the environmental and market networks while the summated network shows that there are relatively low levels of multiplicity among different knowledge fields between system actors (otherwise the summated values would be closer to the different knowledge field values).

As would be hoped, assuming that the system boundaries chosen are valid, the levels of intra-system interactions are far higher than those from system actors to non-system actors (and the full network, as an aggregation of these two levels of inclusiveness is proportionally between with weighting towards the larger number of non-system actors).

7.4.2 Average Ties

The average non-zero tie strength for the interviewed wave energy network system actors (i.e. averaged across all valued active ties and between all system actors) as all network actors (i.e. inclusive of non-system actors) and non-system actors (i.e. from system actors to non-system actors) for the different knowledge types is shown in Table 66.

	Environmental	Technical	Market	Summated
System Actors	6.74	5.63	7.40	6.39
Full Network	6.57	5.93	7.31	6.48
Non-System Actors	6.37	6.27	7.21	6.58

Table 66: Average (non-zero) Tie Value between System Actors, the Full Network and to Non-System Actors

These results are also shown in Figure 98 below:

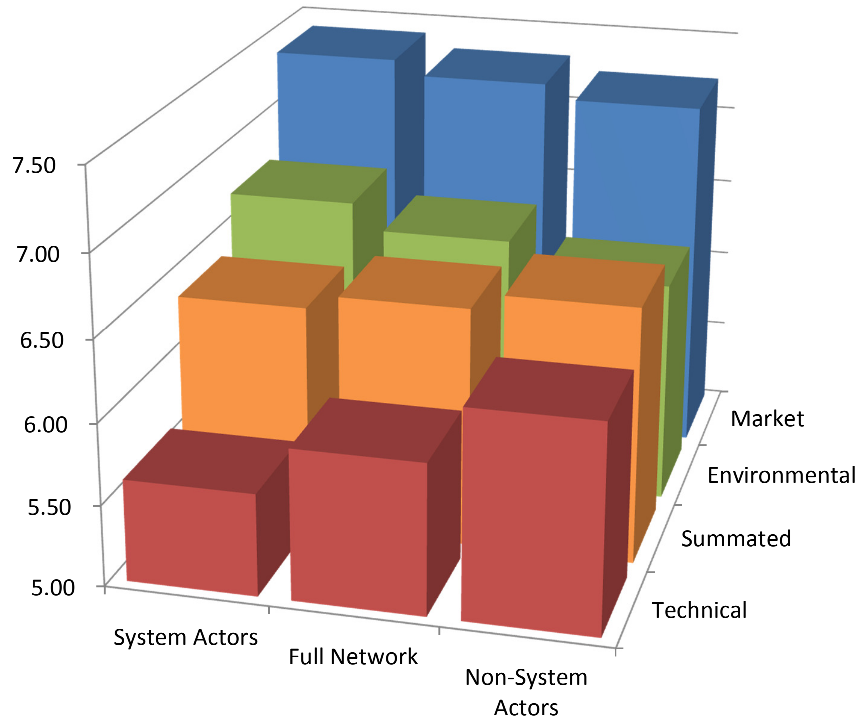


Figure 98: Average (non-zero) Tie Values between System Actors, the Full Network and to Non-System Actors

What Table 66 and Figure 98 show is firstly, that there are higher average levels of interaction within market and environmental fields (despite there being less overall number of interactions within these fields as can be seen from the inclusiveness levels in Table 65). Additionally, those interactions that do occur within both the environmental and market fields tend to be slightly stronger between system actors. Surprisingly however, this is not the case with the technical interactions where (although there are many more inclusive system actors working within this knowledge field,) the figures suggest that these are of lower intensity on average than those to external system actors (such as consultants and component manufacturers).

7.4.3 Density

As stated above, density measures for the network are somewhat misleading since they would be expected to give firstly what would appear to be a very low level of density in comparison to a 'saturated' network of level 10 interaction between all stakeholders within all fields. Secondly because they would only be possible between directly interviewed system actors since non-interviewed actors would clearly not have been available to refer others resulting in a misleading figure in absolute terms. Finally also, because from an interpretive perspective, it would not be expected that there is a linear correlation between over network density and innovativeness of actors since transaction costs and diminishing benefits of connectivity effects take place.

Nonetheless, the data set can be manipulated in the same fashion as used within the individual density measures from the Knowledge Generation and Diffusion section (7.3.1c) of this chapter to allow for a comparative assessment within different groups, (i.e. all Scottish/English or between university/device developer or government actors). This shall provide a valid *relative* level of density measure from which comparison with like groups, (i.e. England-Scotland) can be made.

The main density measure for the different knowledge types for all system actors only is shown within the individual density measures of the Knowledge Generation and Diffusion (7.3.1c) section within this chapter. (NB. These values are far lower than the average tie values provided in Table 66 as they include zero ties in the averaging process as well as all non-system actors.)

Density measures for the different nationalities (for a summated network of system actors only) are shown in Table 67, Table 68 and Table 69 below.

	Sum interaction Value	Density
English	2612	0.1153
Scottish	1930	0.5273
Welsh	0	0
N. Ireland	25	1.25
International	0	0

Table 67: National System Actor Density Measures

		Provider (From)				
		English	Scottish	Welsh	N. Ireland	International
Receiver (To)	English	0.1153	0.0971	0.0464	0.0543	0.0325
	Scottish	0.1146	0.5273	0.0000	0.1443	0.0948
	Welsh	0.0464	0.0000	0.0000	0.0000	0.0000
	N. Ireland	0.1139	0.1410	0.0000	1.2500	0.0667
	International	0.0325	0.0948	0.0000	0.0667	0.0000

Table 68: National System Actor Group Density Measures

		Provider (From)				
		English	Scottish	Welsh	N. Ireland	International
Receiver (To)	English	2612	894	28	41	383
	Scottish	1056	1930	0	44	451
	Welsh	28	0	0	0	0
	N. Ireland	86	43	0	25	26
	International	383	451	0	26	0

Table 69: National System Actor Summated Score Measures

Although data for Wales, Northern Ireland and internationally are less informative (since there are very few if any system actors within these regions), average summated value density score differences between England (0.115) and Scotland (0.527) are significant and show a much higher level of overall intra-national interaction occurring within Scotland than England or clearly the UK overall.

Density measures for the different Stakeholder (for a summated network of system actors only) are shown in Table 70, Table 71 and Table 72 below.

	Sum interaction Value	Density
Final Device Developer	8.00	0.02
Other Comp.	-	-
Utility Com.	30.00	0.42
Central Gov. Dep.	142.00	1.08
Other Public Sector Dep.	4.00	0.00
Uni.	1,181.00	0.27
Test Centre	24	4
Collab. Affil.	302	0.21479

Table 70: Stakeholder Type System Actor Density Measures

		Provider (From)							
		Final Device Dev.	Other Comp.	Utility Com.	Central Gov.	Other Public Sector	Uni.	Test Centre	Collab. Affil.
Receiver (To)	Final Device Dev.	0.0158	0.1231	0.3720	0.5761	0.1978	0.1791	0.8551	0.0847
	Other Comp.	0.1272	0.0000	0.0457	0.0164	0.0058	0.0421	0.3551	0.0492
	Utility Com.	0.3623	0.0457	0.4167	0.5833	0.1528	0.1393	0.5556	0.2515
	Central Gov.	0.6486	0.0164	0.6296	1.0758	0.2333	0.0796	1.6111	0.3904
	Other Public Sector	0.2120	0.0058	0.2528	0.2542	0.0026	0.0474	0.9250	0.1230
	Uni.	0.2135	0.0421	0.1725	0.0709	0.0444	0.2671	0.6866	0.0707
	Test Centre	1.4493	0.3551	2.2963	1.5000	0.7500	0.7065	4.0000	0.6228
	Collab. Affil.	0.0721	0.0492	0.1667	0.4035	0.1066	0.0499	0.4561	0.2148

Table 71: Stakeholder Type System Actor Group Density Measures

		Provider (From)							
		Final Device Dev.	Other Comp.	Utility Com.	Central Gov..	Other Public Sector .	Uni.	Test Centre	Collab. Affil.
Receiver (To)	Final Device Dev.	8	303	77	159	182	276	59	74
	Other Comp.	313	0	44	21	25	302	114	200
	Utility Com.	75	44	30	63	55	84	15	86
	Central Gov.	179	21	68	142	112	64	58	178
	Other Public Sector	195	25	91	122	4	127	111	187
	Uni.	329	302	104	57	119	1181	138	180
	Test Centre	100	114	62	54	90	142	24	71
	Collab. Affil.	63	200	57	184	162	127	52	302

Table 72: Stakeholder Type System Actor Summated Score Measures

Here it can be seen that the highest levels of density are within the three test centres. This is partly to be expected as this is a small population (3 stakeholders) and they are all intrinsically active within the sector and each other. Levels of density within the primary central government departments are second (again this is a small sample) followed by utility companies and then universities (which make up the vast amount of overall communication with a total summated value (based on assumed reciprocity of non-system actors as detailed within the singular density measures outlined within the Knowledge Generation and Diffusion section (7.3.1c) of this chapter) of 1,181. There is very little network density between device developers themselves since they are commercially competitive and 'Other Companies' are not applicable since there were no stakeholders within this category interviewed.

7.4.4 N–Clique

As the process of n-clique analysis requires a binary symmetric data set, the data sets for each knowledge fields was manipulated in the following way:

- Each data set was added with its transposed matrix to create a symmetrised data set.
- Each data set was then dichotomised at four different levels, 1, 3, 6 and 9 (i.e. for the level 6 dichotomisation, a singular directed relationship of 6 or above or a combinational relationship of 3 (reciprocally) or above was dichotomised into a binary symmetric data set of 1 etc.)
- For the summated network, the process of summation occured *before* the matrix was symmetrised and dichotomised to ensure those networks which are present within singular knowledge fields are still present within the summated network.
- The resulting clique count was then normalised against the number of representatives within that group (i.e. nationality or stakeholder type) who were interviewed to provide a relative reference (i.e. since many more universities and device developers have been interviewed, one would expect to find a higher levels of cliques than the three test centres, normalising accounts for this).

N-Clique analysis was done with an n setting of 2 (i.e. permissible clique path distance between member nodes of 2) and a minimum clique allowance of 3 (i.e. 3 nodes or above create a clique) see n-clique analysis within the literature review (section 2.4.2e) for further information on these variables.

Results from the analysis are shown in Figure 99, Figure 100 and Figure 101 below:

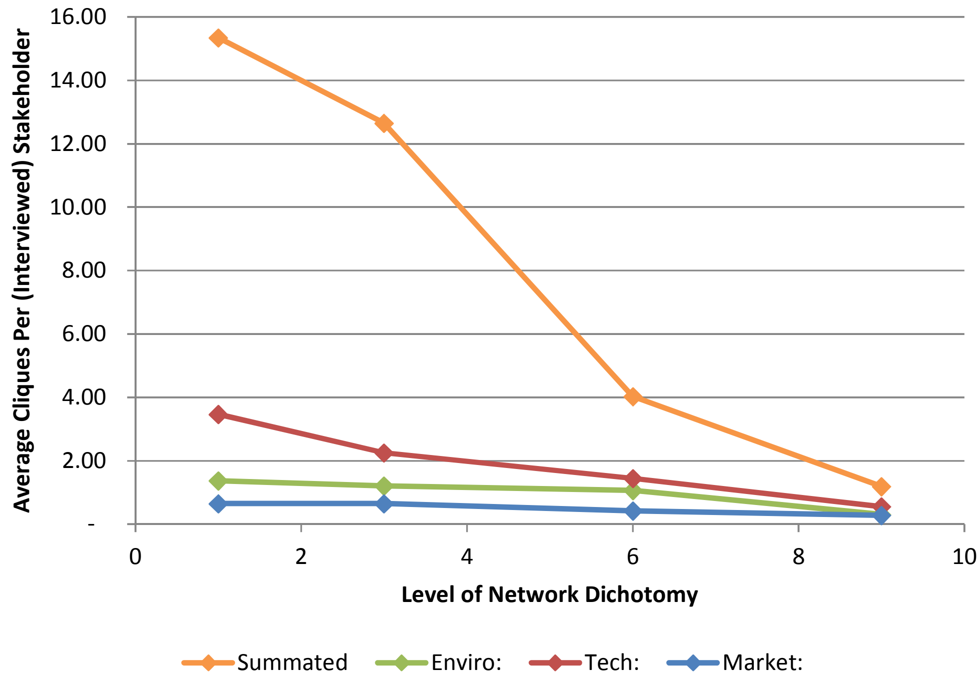


Figure 99: Total Knowledge Network Clique Levels

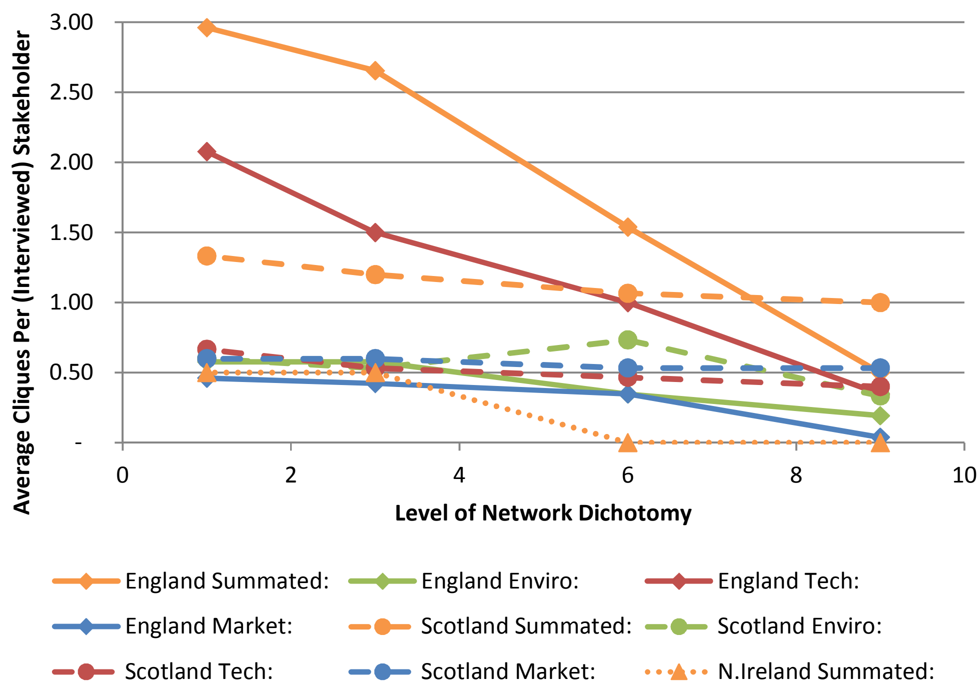


Figure 100: Knowledge Network Clique Levels by Nationality

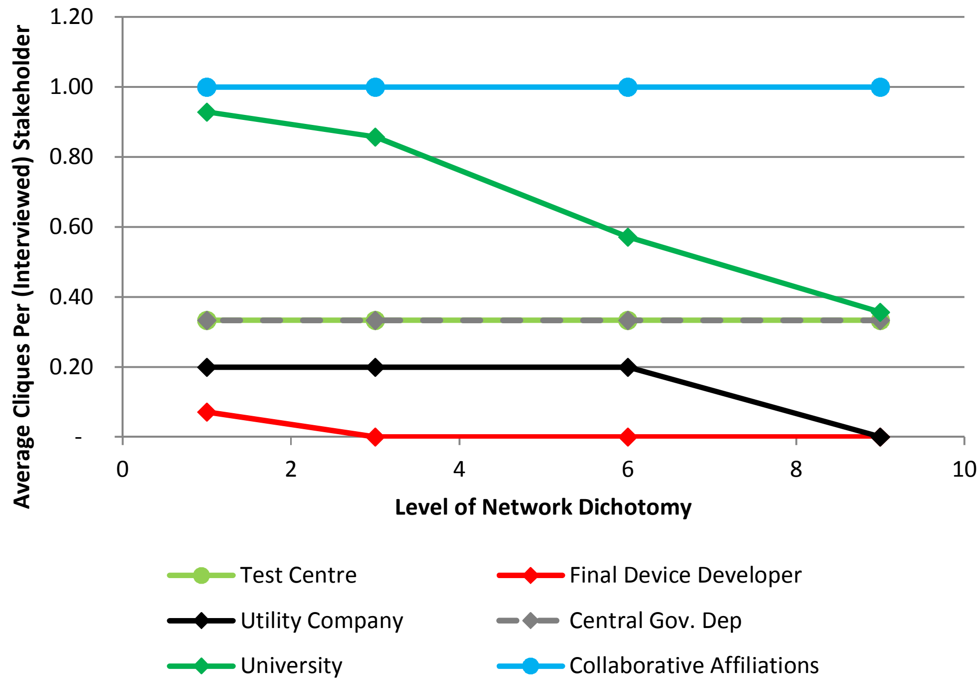


Figure 101: Knowledge Clique Levels by Stakeholder Type[3]

The above figures show an interesting indication of the level of network structure between the different knowledge types as well as internal to national and stakeholder type activities.

Figure 99 clearly shows a higher level of cliques within the technical knowledge field followed by the environmental and finally market fields. This is roughly expected given the overall level of interaction occurring within these fields.

However, Figure 100 shows that England has a far higher level weak (i.e. intensity below 6) internal cohesion within its technical network than Scotland but Scotland has higher levels of strong (i.e. 6 and above) internal cohesion within both the environmental/planning and market/fiscal network. This latter point is most likely due to the high levels of work being conducted within both EMEC and the Pentland Firth development. The aforementioned levels of internal technical clique however show that despite having clearly the most influential research institute within the network, (the University of Edinburgh), the levels of network communication and interaction within Scotland are not as balanced in distribution as those within England.

[1] N.B. only interviewed stakeholder types are included within the analysis

There are a few reasons for this, mainly that the University of Edinburgh's research interactions are both international in nature and between a wider array of stakeholders (where as many of England's universities work very heavily with other English universities) and secondly that, outside of Edinburgh, although there are several high performing universities within the sector (which normalise the score) they are on average collaborating far less within the technical field of wave energy sector than English universities are. Figure 102 below illustrates this graphically with the technical network.

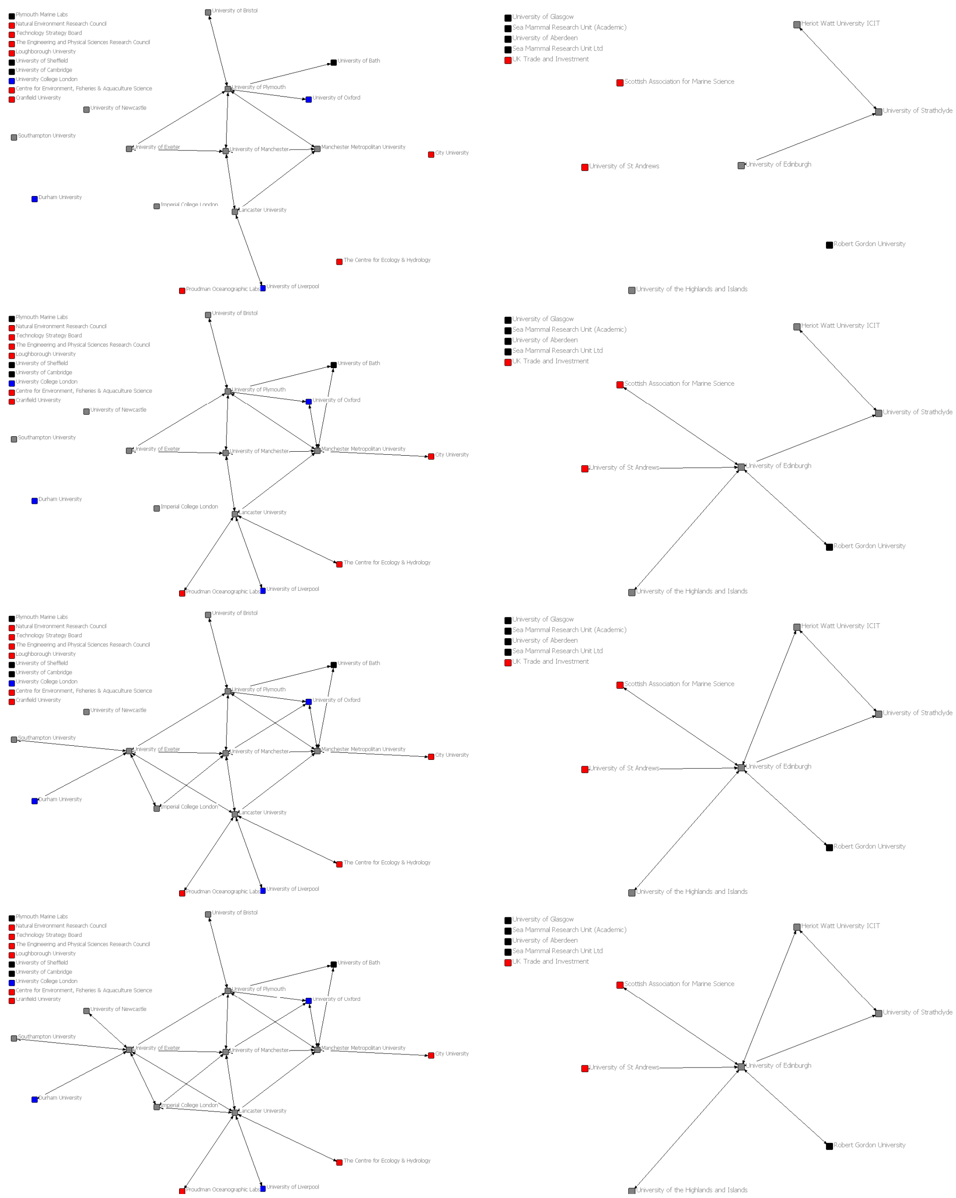


Figure 102: National University, Technical Knowledge Network Comparisons with England on the Left & Scotland on the Right, Running through Dichotomisation Levels of 9, 6, 3 and 1 Sequentially From the Top.

The levels of cross-network membership can also be visualised using 2 mode network analysis as shown in Figure 103 below.

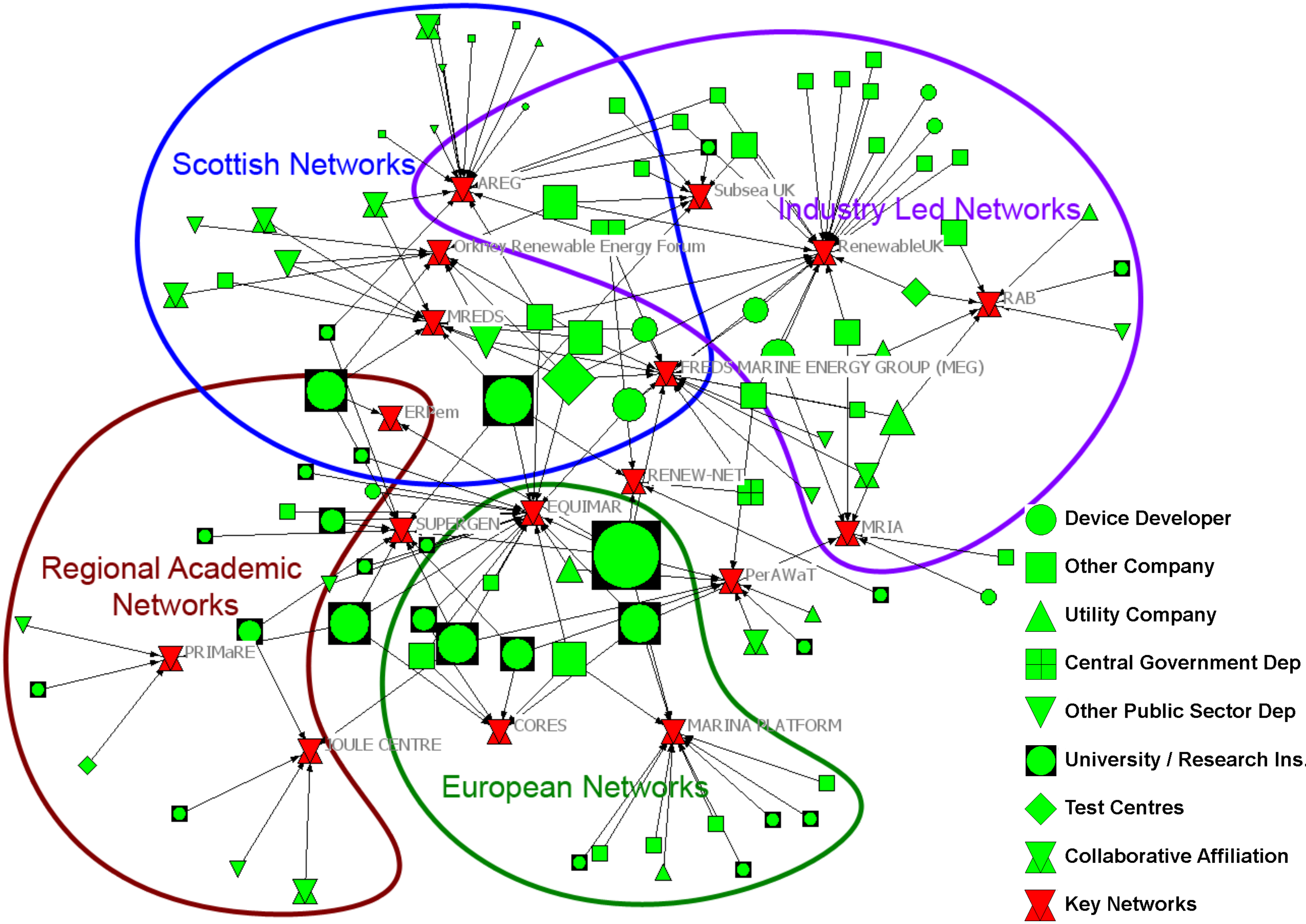


Figure 103: 2 Mode Network Showing Relation of Established Networks (Proximity is Based on Mutual Membership while Size of Node is Based on Quantity of Memberships)

As can be seen, there is some level of homophily to the network memberships within established networks which can be roughly sub divided into the four visual categories; Regional Academic Networks, European Networks, Industry Led Networks and Scottish Networks. This form of visualisation helps to show the level of overlap and similarity between established network types as well as providing an overview as to the profile of these networks memberships.

7.4.5 Homophily

One of the measures that can be employed to assess the measure of inter-group type interaction is that of homophily (Krackhardt and Stern, 1988). Homophily measures allow for an assessment as to the level of inter to intra group interaction for stakeholder types as well as different nationalities ranging from +1 (which equates to a fully heterogeneous level of interaction) to -1 (which equates to a fully homophilous level of interaction). Since the input data set for this analysis is both valued and directed (showing who the ‘chosen’ interaction is with rather than the flow of knowledge), the primary data set can be used with no modification. All actors can be included since if stakeholders have chosen non-interviewed actors of a different stakeholder type/nationality, this will show as a higher level of heterogeneity regardless of the non-interviewed actors response.

Results for the homophily tests are show in

	Environmental	Technical	Market	Summated
Nationality EI Index	0.303	0.262	-0.037	0.181
Stakeholder EI Index	0.638	0.418	0.398	0.472

Table 73 below.

	Environmental	Technical	Market	Summated
Nationality EI Index	0.303	0.262	-0.037	0.181
Stakeholder EI Index	0.638	0.418	0.398	0.472

Table 73: Homophily Indicators for Different Nationalities and Stakeholder Networks

What

	Environmental	Technical	Market	Summated
Nationality EI Index	0.303	0.262	-0.037	0.181
Stakeholder EI Index	0.638	0.418	0.398	0.472

Table 73 shows surprisingly, is that there is a higher generally level of heterophily between the nationalities than homophily. This is only not the case with the market/fiscal network which could be as a result of the high national focus of primary and devolved support funding bodies. With reference to the stakeholder types, this shows that the highest level of heterogeneity occurs between stakeholder types and most prominently within the technical knowledge field (i.e. technical interactions between universities and device developers for example).

7.5 Development of Positive Externalities

7.5.1 Externally Sourced Knowledge

The main indicator available for the development of positive externalities with regards to the defined system boundary is the ratio of externally sourced knowledge in-flow against that of the internal knowledge flow within the system. If the system is acquiring a great deal of knowledge (through interaction) from international universities, then this is a clear indicator that these universities are providing complimentarily to the sector. Clearly, where the system boundary is located can be argued subjectively (as in any innovation systems analysis) however within this study the 'system' is considered to be represented by UK based stakeholders (both interviewed and not interviewed) as detailed within Chapter 5, Methodology section (5.3). As such, the level of externality-benefit can be assessed for different sub-groups of actors specifically: UK based non-system actors, non-UK based (non-system) actors and all combinations of both stakeholder type and knowledge flow type within these categories.

Since the information is required to represent knowledge in-flow, the matrices shall be transposed for analysis. Findings from the analysis are shown in Table 74 and Table 75 below.

	Externally Sourced (Non-System Actor	Internally Sourced (System Actor)
Enviro	631	815
Tech	1073	1126
Market	808	814
Summated	2512	2755

Table 74: Key Externality/Internality Measures

	Externally Sourced (Non-System Actor	Internally Sourced (System Actor)
Environmental/Planning		
Nationality of Source		
England	243	277
Scotland	212	521
Wales	8	0
N.Ireland	0	17
International	168	0
Stakeholder Type of Source		
Final Device Developer	2	74
Other Company	196	0
Utility Company	9	73
Central Government Department	7	199
Other Public Sector Department	196	179
University	111	182
Test Centre	0	98
Collaborative Affiliations	110	10

	Externally Sourced (Non-System Actor	Internally Sourced (System Actor)
Technical		
Nationality of Source		
England	435	589
Scotland	138	478
Wales	8	0
N.Ireland	5	59
International	487	0
Stakeholder Type of Source		
Final Device Developer	33	202
Other Company	594	0
Utility Company	8	82
Central Government Department	10	36
Other Public Sector Department	39	43
University	371	590
Test Centre	0	133
Collaborative Affiliations	18	40

	Externally Sourced (Non-System Actor	Internally Sourced (System Actor)
Market/Fiscal		
Nationality of Source		
England	353	387
Scotland	220	405
Wales	0	12
N.Ireland	30	10
International	205	0
Stakeholder Type of Source		
Final Device Developer	25	114
Other Company	229	0
Utility Company	0	106
Central Government Department	23	252
Other Public Sector Department	253	97
University	83	112
Test Centre	0	66
Collaborative Affiliations	195	67

	Externally Sourced (Non-System Actor	Internally Sourced (System Actor)
Summated		
Nationality of Source		
England	1031	1253
Scotland	570	1404
Wales	16	12
N.Ireland	35	86
International	860	0
Stakeholder Type of Source		
Final Device Developer	60	390
Other Company	1019	0
Utility Company	17	261
Central Government Department	40	487
Other Public Sector Department	488	319
University	565	884
Test Centre	0	297
Collaborative Affiliations	323	117

Table 75: Externality/Internality Breakdown for all Knowledge Types

As can be seen from the summated figures in Table 74, the system boundary encapsulates the majority of overall interactions. However, a large proportion of all knowledge comes from external sources. This is (understandably) specifically true for 'other companies' and 'international sources since these are (by system definition) external to the system.

The histogram in Figure 104 below shows a more detailed breakdown of the environmental and planning knowledge flows from external actors.

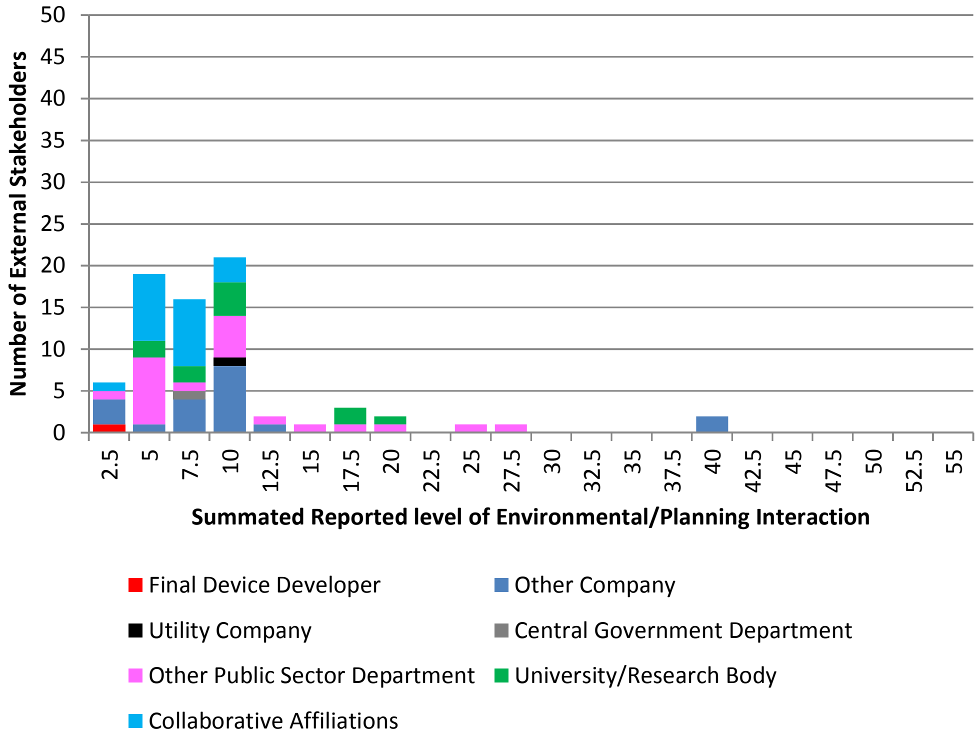


Figure 104: Profile of Environmental/Planning Externality by Stakeholder Type

Looking at the breakdown of externalities further it can be seen that in the environmental field, these externalities come mostly from English non-system actors, 'other public sector departments', (pink) and 'other companies' (lilac). Specifically the environmental consultancies Aquatera and Xodus have an individually summated level of interaction referenced at 40 and 39 respectively (compared with DECC who provide 49). Xodus has historically originated within the oil and gas industry and both having worked extensively within offshore wind. Other prominent national actors include the public sector bodies of the Highlands and Islands Agency, (26) and the Orkney Islands Council (20). In England there is a more evenly distributed level of external contribution with the most prominent support provision coming from the public sector body, the Centre for Environment, Fisheries & Aquaculture Science (17). Internationally, the highest scoring actor is the EU-OEA (23) but again, the distribution of environmental support is more dispersed than within Scotland.

The histogram in Figure 105 below shows a more detailed breakdown of the technical knowledge flows from external actors.

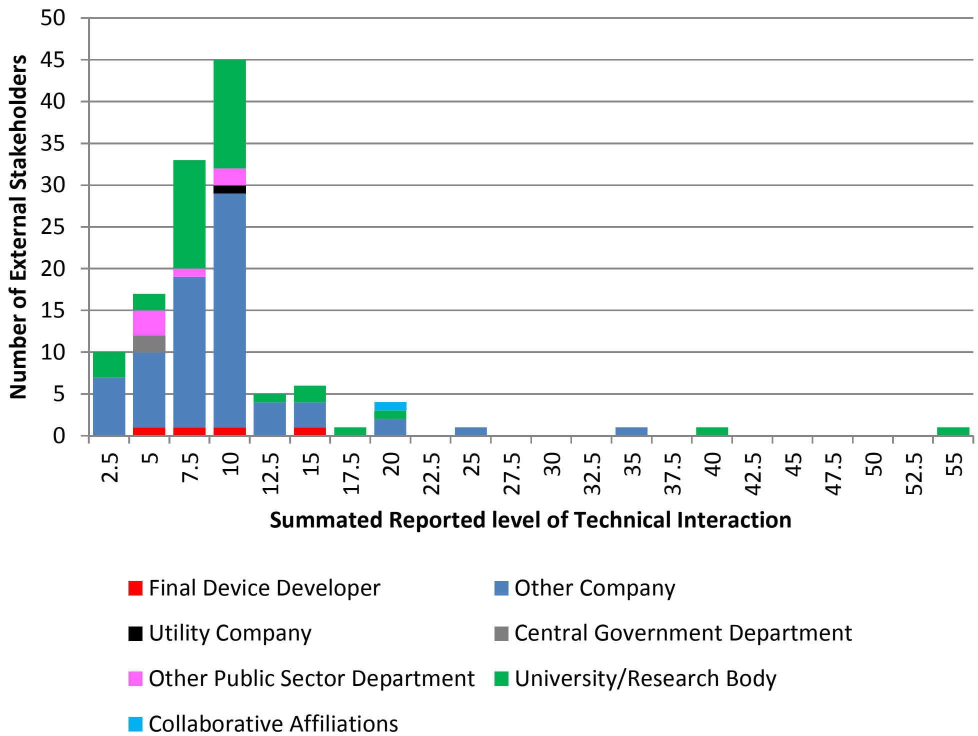


Figure 105: Profile of Technical Externality by Stakeholder Type

Within the technical fields of contribution, international and English stakeholders provide the highest level of contribution, specifically a wide array of international companies and universities. Most notable of these is the Hydraulics and Maritime Research Centre (HMRC) at the University College Cork (55) which, although technically outside of the system boundaries, (being in the Republic of Ireland) is still a large technical contributor to the sector. The University of Oxford (38) also scores surprisingly well (given that they reported having only one PhD student working within wave energy at the time of the primary data gathering), this may be because people had historically been involved within the sector at Oxford (and were referenced from some years ago) or that there was some mis-representation based on their involvement within the PerAWat project (in which they are researching tidal technology). Other national and international contributors include GL Garrad Hassan (35) who have a specialised history in wind energy consultancy and turbine software development and DNV (24) who have an international pedigree within both maritime and oil and gas research and risk management. Other primary contributors include Atkins (20) the British Standards Institute (BSI) (18) and the Université de Nantes (17)

Finally, the histogram in Figure 106 below shows a more detailed breakdown of the market and fiscal knowledge flows from external actors

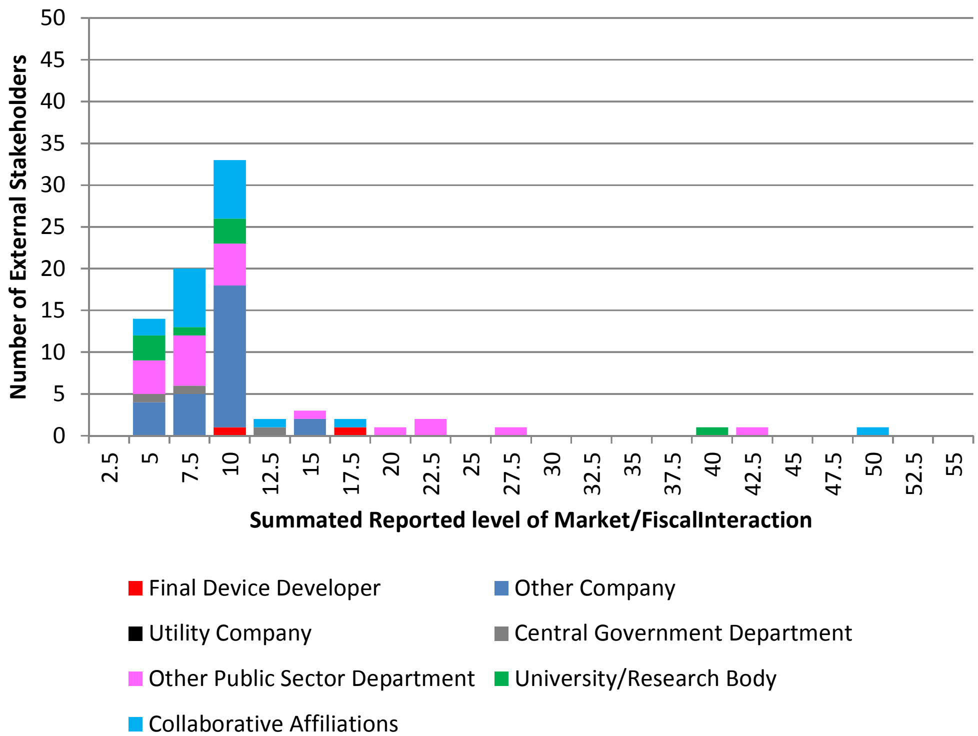


Figure 106: Profile of Market/Fiscal Externality by Stakeholder Type

Within the market and finance field, there is a high level of external Scottish (mainly public sector) contribution, from bodies such as industry association Scottish Renewables (48), Highlands and Islands Enterprise (42) and Scottish Development International (18). Despite this large (and centralised) level of support from the Scottish public sector, the English market provides the most aggregate support through the Technology Strategy Board (39), South West Regional Development Agency (SWRDA) (27) and the National Grid (15) as well as a large array other stakeholders mainly consisting of private companies (specifically utilities), regional development agencies and collaborative networks (such as the Society for Underwater Technology, Marine Renewable Energies Committee, Associate Parliamentary Renewable and Sustainable Energy Group etc.).

7.5.2 Other Observations

While looking at the profile of external contributors to the sector, those missing actors are perhaps more telling than those present. Most obvious of these are non-system marine development test centres (such as the Pico Test Plant, the Portuguese Pilot Zone or the various early stage Spanish test sites). Although many of these sites are either non-research bodies within their own right (e.g. there is no Portuguese Pilot Zone research centre) or are looking at OWC technology which is not heavily represented within the UK, it is still interesting to note that no UK stakeholders directly reference these projects as a source of interaction. Additionally, there is very little interaction with non-national device developers other than a few relatively low strength (from a whole network perspective) interactions specifically with test centres. Although there are clearly far fewer international device developers than, universities and 'other companies', only 6 were referenced out of a potential 100 or so, (identified within the Entrepreneurial Experimentation section (6.9.2) within chapter 6, Established Findings).

7.6 Entrepreneurial Experimentation

Entrepreneurs within innovation analysis have something of a different focus within network analysis understandings than that of current established innovation theory. As discussed within the literature review, within innovation literature, entrepreneurship has become far more focussed on the creation and diffusion of an innovation itself (be it a product or process) (Fagerberg *et al.*, 2005, Desrochers and Sautet, 2008). The Schumpeterian perspective of entrepreneurs as forces for 'creative destruction' including the gaining of access to new sources of supply and exploitation of new markets, have conceptually been distinguished further into diffusion theory and away from the entrepreneur themselves (Schumpeter, 1934, Nelson *et al.*, 2004). Within network analysis however this historical decoupling is readdressed and entrepreneurs are considered to be actors who profit from exploiting the opportunities of the marker through brokerage between others. This is further defined by Burt as *tertius entrepreneurs* or simply *tertius* from the Latin 'third' (since they are the third actor within an exchange) (Burt, 1992). These two definitions for both innovation and those that innovate (the entrepreneurs) are clearly not exclusive, however the tools that are used to access entrepreneurial activity do need to be addressed separately as, while one form of entrepreneurship focuses upon the diffusion of new things (as distinct from the inventor who creates the new thing) the other, that associated with the relationships within supply chains and new markets, focuses upon exploitation of opportunity (i.e. network or market brokerage and exploitation).

The social network analysis measures of entrepreneurial activity, for obvious reasons, are viable only for these latter forms of innovation and there are two primary methods of analysis that can be applied. The first, effective brokerage (Gould and Fernandez, 1989b) provides an indication as to the diversity of interactions with which an actor is engaged in and thus, (applying Jacob's theory of knowledge spill-over from diversification (Jacobs, 1969) some proxy for its innovative opportunity as well as an insight into the key interacting agents between different sub-groups. The second set of measures, redundancy and constraint, are ego-centric based measures for the level of relationship control and dependency that individual actors possess. Both are discussed further within sections 2.42b and 2.44a respectively within the Literature Review chapter (Chapter 2).

7.6.1 Structural Holes

Burt's measures of redundancy and constraint are designed for directed (asymmetric) valued data. As well as this, the ties defined within the measures of structural connectivity relate to the resource dependency relationship between ego and alter. As such, these brokerage measures are suitable for the (un-processed) network data provided from the primary data gathering stage.

The insight provided by network redundancy is somewhat less valuable than would be for more mature industry network where actors would be competing for supply chain reduction and markets since the nature of the interactions taking place within the industry at this scale are both more diverse (in that the supply chain and distribution aspect of the network is a much smaller element), and more explorative (in that they are in many cases 'problem solving' network). This means that relations are not simply 'substitutable' with other actors as is the premise of structural hole metrics (Burt, 1992).

Measures are taken using an ego-network model only (i.e. at a path distance from ego of 1) with bi-directionality. Only interview respondents are shown within the findings (since system actors are of prime interest within the study and those not interviewed will have an erroneously higher level of constraint than those who have reported interactions).

The top 10 largest effective sizes and most constrained actors for the different knowledge networks are shown in Table 76 below. Since the constraint measure reflects a relative level of constraint, and not all actors list themselves as being active within all knowledge fields (i.e. the Marine Management Organisation does not claim to have any technical interactions and many universities do not have any market/fiscal specific interactions), the top 10 rankings are listed *only* for respondents who claim to have interactions within that specific knowledge field (i.e. a weighted out degrees >0). As a result of this, the summated measure becomes superfluous as it summates measures of constraint for actors over all fields, including ones in which they claim not to be active, and the insight of including this table for actors who claim to be active within all fields would itself be limited.

Most Technical Effective Size		Technical		Market/Fis.		Enviro./Plan.	
Rank	Stakeholder	Eff. Size	Cons.	Eff. Size	Cons.	Eff. Size	Cons.
1st	University of Edinburgh	69.7	0.04	8.21	0.33	4.65	0.53
2nd	University of Exeter	27.58	0.14	2.45	0.69	3.86	0.5
3rd	University of Manchester	21.11	0.17	1	1	1	1
4th	narec	20.57	0.22	1.62	1.21	2.45	0.86
5th	EMEC	17.8	0.17	6.73	0.47	43.53	0.08
6th	Manchester Metropolitan Uni.	16.91	0.16	1	-	1	-
7th	EDF Energy	15.89	0.24	2.73	0.93	1	1
8th	Queen's University Belfast	15.28	0.23	1	1	1.05	1.15
9th	Pelamis Wave Power Ltd	13.69	0.22	13.91	0.21	10.69	0.24
10th	Lancaster University	12.33	0.24	1	1	1	1

Most Technical Constrained		Technical		Market/Fis.		Enviro./Plan.	
Rank	Stakeholder	Eff. Size	Cons.	Eff. Size	Cons.	Eff. Size	Cons.
1st	Pure Marine Gen Ltd	5.18	0.62	2	0.5	1	-
2nd	Imperial College London	6.03	0.55	1	1	1	-
3rd	University of Newcastle	3.23	0.51	1	1	1	-
4th	Embley Energy Ltd	5.62	0.51	2	0.5	1	-
5th	FreeFlow 69 Ltd	2	0.5	2	0.5	1	1
6th	Trafalgar Marine Technology Ltd	5.17	0.49	1	-	1	-
7th	Scottish and Southern Energy	5.89	0.48	5.46	0.49	5.46	0.53
8th	Offshore Wave Energy Ltd	5.84	0.37	3.09	0.35	1	-
9th	Green Cat Renewables Ltd	3.18	0.35	1.11	1.08	1	-
10th	Southampton University	10.51	0.35	1	-	1	1

Most Market/Fiscal Effective Size		Technical		Market/Fis.		Enviro./Plan.	
Rank	Stakeholder	Eff. Size	Cons.	Eff. Size	Cons.	Eff. Size	Cons.
1st	RenewableUK	9.92	0.16	88.26	0.03	29.23	0.06
2nd	Scottish Government	1	1	18.55	0.19	2.13	0.83

3rd	Marine Scotland	10.13	0.13	18.01	0.12	18.65	0.18
4th	Pelamis Wave Power Ltd	13.69	0.22	13.91	0.21	10.69	0.24
5th	E.ON	8.82	0.34	10.73	0.35	6.06	0.42
6th	University of Edinburgh	69.7	0.04	8.21	0.33	4.65	0.53
7th	EMEC	17.8	0.17	6.73	0.47	43.53	0.08
8th	Aquamarine Power	10.1	0.26	6.22	0.43	2.68	0.68
9th	Scottish and Southern Energy	5.89	0.48	5.46	0.49	5.46	0.53
10th	Trident Energy Ltd	7.44	0.28	5.27	0.22	4	0.25

Most Market Fiscal Constrained		Technical		Market/Fis.		Enviro./Plan.	
Rank	Stakeholder	Eff. Size	Cons.	Eff. Size	Cons.	Eff. Size	Cons.
1st	Uni. of the Highlands & Islands	1	1	1.12	1.19	17.48	0.21
2nd	Green Cat Renewables Ltd	3.18	0.35	1.11	1.08	1	-
3rd	University of Manchester	21.11	0.17	1	1	1	1
4th	EDF Energy	15.89	0.24	2.73	0.93	1	1
5th	University of Strathclyde	10.38	0.29	1.72	0.89	1	1
6th	University of Exeter	27.58	0.14	2.45	0.69	3.86	0.5
7th	Ocean Wave Master Ltd	6.65	0.26	2.17	0.59	1	-
8th	Green Ocean Energy	9.19	0.17	4.61	0.59	2.12	0.51
9th	Wave Hub	8.92	0.17	4.94	0.56	14.1	0.17
10th	Ocean Power Technologies	7.6	0.28	3.93	0.52	8.13	0.28

Most Enviro./Planning Effective Size		Technical		Market/Fis.		Enviro./Plan.	
Rank	Stakeholder	Eff. Size	Cons.	Eff. Size	Cons.	Eff. Size	Cons.
1st	EMEC	17.8	0.17	6.73	0.47	43.53	0.08
2nd	RenewableUK	9.92	0.16	88.26	0.03	29.23	0.06
3rd	Marine Scotland	10.13	0.13	18.01	0.12	18.65	0.18
4th	Uni. of the Highlands & Islands	1	1	1.12	1.19	17.48	0.21
5th	Scottish Natural Heritage	1	-	1	-	16.86	0.25
6th	Heriot Watt University ICIT	8.32	0.33	3.12	0.34	15.35	0.17
7th	Wave Hub	8.92	0.17	4.94	0.56	14.1	0.17
8th	Crown Estate	1	1	1.32	0.93	13.32	0.23
9th	University of Plymouth	11.46	0.25	2	0.5	10.72	0.12
10th	Pelamis Wave Power Ltd	13.69	0.22	13.91	0.21	10.69	0.24

Most Enviro./Planning Constrained		Technical		Market/Fis.		Enviro./Plan.	
Rank	Stakeholder	Eff. Size	Cons.	Eff. Size	Cons.	Eff. Size	Cons.

1st	FreeFlow 69 Ltd	2	0.5	2	0.5	1	1
2nd	Scottish Government	1	1	18.55	0.19	2.13	0.83
3rd	Aquamarine Power	10.1	0.26	6.22	0.43	2.68	0.68
4th	University of Edinburgh	69.7	0.04	8.21	0.33	4.65	0.53
5th	Scottish and Southern Energy	5.89	0.48	5.46	0.49	5.46	0.53
6th	Green Ocean Energy	9.19	0.17	4.61	0.59	2.12	0.51
7th	University of Exeter	27.58	0.14	2.45	0.69	3.86	0.5
8th	E.ON	8.82	0.34	10.73	0.35	6.06	0.42
9th	RWE Npower	7.54	0.34	1.08	1.33	5.68	0.3
10th	Ocean Power Technologies	7.6	0.28	3.93	0.52	8.13	0.28

Table 76: Most Structurally Efficient and Constrained Actors within the Network

Interpreting the results from the structural hole analysis is somewhat less straight forwards due to the diversity and non-substitutable aspects of each relationship. Certain elements however strongly stand out within the analysis, such as the fact that device developers (particularly those of less mature technology) appear very much constrained with 6, 4 and 4 of the top 10 constrained stakeholders being device developers within the technical, market/fiscal and environmental/planning networks respectively.

Although one might expect to see an inverse proportional relationship between a device developer's technology readiness level and their level of structural constraint, there is only a fairly loose correlation (-0.2 Tech, -0.88 Market, -0.71 Enviro), as can be seen from Figure 107 below.

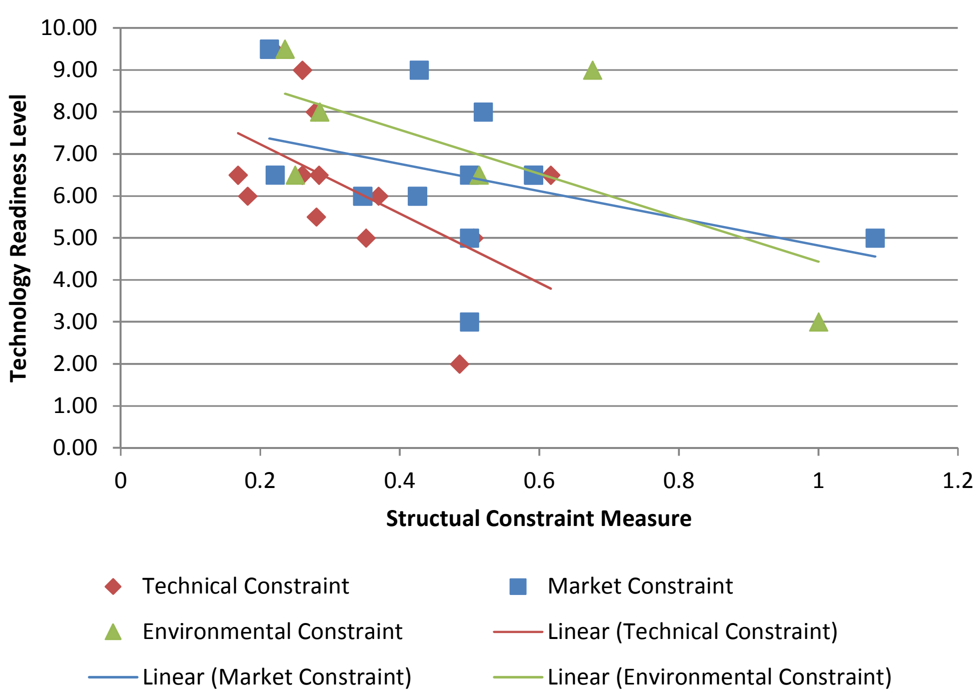


Figure 107: Technology Readiness Level Correlation with Structural Constraint for Device Developers

When analysing the level of effective network size against technology readiness level, the expected linear correlation is clearer (0.81 Tech, 0.75 Market, 0.69 Enviro) but still not strong enough to be conclusive as can be seen from Table 76 below:

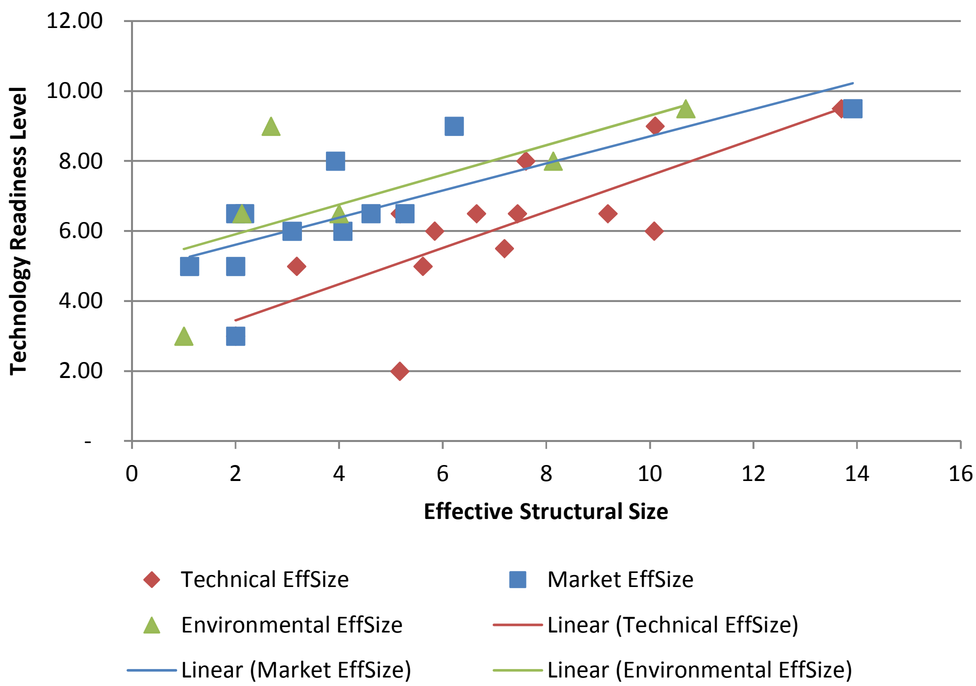


Figure 108: Technology Readiness Level Correlation with Effective Network Size for Device Developers

Other observational points that can be made regarding actors size and constraint include the clear observation that universities and test centres have high technical effective size, there is a more heterogeneous mix of actors within the most effectively sized market/fiscal network and Scottish public sector bodies and universities hold the highest effective size within the environmental network.

With regards to constraint; as mentioned above, device developers are heavily constrained, (especially non-mature developers) as well as peripherally involved universities (such as Imperial College and the University of Newcastle) although interestingly Southampton University (a leading technical institute within the sector), appears at the bottom of the technically constrained table. Many universities also appear within the market/fiscal constraint table which, given their little involvement within this field, seems understandable. The environmental constraint table however shows an interesting diverse mix of actors with a fairly wide range of constraints. Again, many of these actors are peripherally involved with environmental/planning aspects, (such as the Scottish government who devolve planning responsibility to Marine Scotland or University of Edinburgh which in far more focussed upon technical interactions).

7.7 Conclusive Remarks

This chapter has used social network analysis to conduct an original analysis of the UK wave energy sector within the framework of the TIS approach. A discussion on these findings, (as well as all the primary metrics); their appropriability, validity, ease of acquisition and use, can be found within the following Methodological Discussion section (chapter 9) as well as - to a lesser degree, the System Discussion section (chapter 10) which addresses the narrative findings of the sector itself. Before this however, there is a very brief chapter that has been included which simply states some of caveats and exceptions which are acknowledged within this body of work and are included for both completeness, (in terms of an acknowledgement of the limitations of this field of study) and context of findings (in terms of acknowledgement of the surrounding and related issues which should be addressed within the wider policy framework before making normative policy statements, (such as issues of carbon abatement etc)).

8. Caveats and Exceptions: What This Thesis is not about

8.1 Chapter Introduction

Any research programme must set boundaries as to the depth, scale and scope of investigation that is undertaken. This brief chapter is intended to highlight specific boundaries and caveats within the research that are consciously made as well as providing validation for these decisions. Some of these are decisions are based on natural boundaries of investigation while others are consciously decided so as to limit the scope of the research project such that it is manageable within both the timeframe and academic requirements of a study of this type.

8.2 Environmental Assumptions and Justifications

8.2.1 Presumption of Climate Change Evidence

This research (while assessing methods for increasing understanding, and thus more effective promotion of renewable energy technology innovation) does not focus on the background technical details of climate science or climate change. Neither does it focus on the anthropogenic contributions towards this change or indeed the sociological questions of how best to address this global change (except in so far as to promote efficacy in policy decisions relating to renewable energy). The assumptions made within this research are (as provided by the Intergovernmental Panel on Climate Change) that since the mid 20th century, observed increases in global temperatures are very likely (i.e. to a 95% confidence interval) to have been caused by human greenhouse gas emissions (IPCC, 2007b).

8.2.3 $C0_2$ Savings

Clearly, one of (if not *the*) primary goal and motivation behind the commercialisation of wave energy technology is to assist in the reduction/mitigation of GHG emissions from the energy generation sector (specifically electricity). Given the UK average of 0.545 kg of CO2e per kWh (for grid electricity) and estimates for capacity and availability factors of different devices & projects, it would not be especially complicated to estimate an operational CO2 savings per device (Carbon Trust, 2011b). It is not however within the remit of this work to justify conducting this research although it is acknowledged that if technology specific policy funding suggestions were being made, a cost/kg of CO2 analysis would be a crucial factor.

8.2.4 Life Cycle Analysis

More complex than a CO_2 savings analysis would be to do an environmental (or indeed cost) lifecycle analysis. The main reason for this is simply due to both commercial sensitivity of equipment and lack of deployment experience by the device developers. More specifically though, this is again outside of the considered remit of this research however, as with a CO_2 savings analysis, it is acknowledged that for technology specific funding, this form of analysis would be a factor.

8.3 System Boundaries

8.3.1 Scope of System Research

As described within the methodology, this research focuses on the innovation of wave energy devices for electrical generation. During some of the research findings however due to aggregation of data available, the scope of data gathered exceeds this boundary and refers to both 'Marine Renewable Energy' (i.e. wave, tidal current and only where specified tidal barrage/lagoon energy technology (RenewableUK, 2010a, Scottish Government, 2010b, European Ocean Energy Association, 2010)) and 'Ocean Energy' (i.e. tidal power, wave, ocean current, ocean thermal and 'other' (IEA, 2009)). Although the overall impact upon findings of this necessary broadening is considered to be low, the *specific* resolution of information, as proxy indicators of functionality is clearly adversely affected, (e.g. statistics for expected employment forecasts within the marine energy sector do not provide anywhere as clear an insight as wave energy only statistics).

8.3.2 Scale of System Research

Although this research does cover Northern Ireland, it is acknowledged that their respective legal, electrical, innovation and marine planning institutions are somewhat different from that of Great Britain and that the technical aspects of these differences are not explored in great detail due to research limitations. Key stakeholders (Queen's University Belfast and Pure Marine Energy) are heavily integrated into the GB wave energy sector however and have thus been included as survey respondents. It is also acknowledged that despite certain key stakeholders (such as University College of Cork within Ireland) being involved within the GB wave energy sector it has consciously been decided that for both clarity of system boundaries and methodological rigour that these (non-UK parties) would be excluded.

8.3.3 Timeframe of Research

Interviewees were questioned over the period from 12th April 2010 until the 16th of February 2011 and were asked to give information on what interaction that their institution had participated in over the past 3 years. This research should therefore reflect (roughly) the levels of interaction within the industry from April 2007 until February 2011. Given the fast moving pace of change within marine policy, the background review of the sector and established findings indications are (again roughly) accurate up until a similar timeframe (i.e. June 2011).

8.4 Academic Boundaries

8.4.1 Systems of Innovation

Systems of innovation as well as broad methodological approaches of analysis have been identified by a wider range of academic writers (see section 2.3.3 Types of Innovation System within the Literature Review chapter for further details). This research specifically did not intend to 're-invent the wheel' by creating diversification of analytical frameworks when there is clearly a wider range of analytical approaches already present. Instead of this, the research has sought to take a specific and highly operational methodology, namely Technological Innovation Systems (Bergek *et al.*, 2008a) to apply and assess the innovation indicators available as well as build upon them using the addition of network analysis. The applicability of network analysis (or indeed many of the other 'established' indicators of innovation) is not confined to the technological innovation systems approach alone however and should be thought of rather as different operational indicators for analysis of 'innovation' and 'innovation systems' in general rather than for any one analytical methodology.

8.4.2 Social Network Analysis

Social Network Analysis (SNA) as a relatively recent field of study (see Social Network Analysis section 2.4 of the Literature Review chapter for more details) is used from both a purely theoretical perspective (e.g. finding new metrics and methods of network analysis) as well as being applied as a tool of analysis (e.g. within epidemiology or policy analysis for example). The work presented here is clearly within the latter category of research application, however a deep understanding of both the theory and application is considered to be required to ensure that application of this tool is appropriate and that theoretical assumptions (such as those underlying centrality metrics or network horizons for example (Freeman, 1978, Anderson *et al.*, 1994)) are applicable and taken into account when applied to the forms of relationships under analysis (i.e. organisational interactions).

8.5 Conclusive Remarks

This chapter has discussed the caveats and exceptions that have been considered practical for the operational necessity of this research. These exceptions are acknowledged as potential avenues of research or areas of interest that would have provided further insight into either methodology or the system should research resources have provided for them. Their exclusion however is not expected to detriment the overall findings of this research which are now explored further within the final two chapters of this thesis, chapter 9, the Methodology Discussion Chapter, and chapter 10, the System Discussion Chapter.

9. Methodology Discussion

Table of Figures:

Table of Tables:

9.1 Chapter Introduction

This chapter seeks to address the first two of the primary research questions as outlined within the research question chapter (section 4.2). Specifically these are: How can we come to a clearer understanding of early stage technological innovation systems through robust and transferable measures of key emergent system functionalities, and: How insightful are the various methodologies for system functionality analysis, and how replicable are they. The answer to both of these questions is presented as pertaining to the *methodology* of this research below in a thematically logical way in which the two key yet separate research methodologies are identified and discussed.

The first of these is a critique of the established metrics for innovation systems analysis. It identifies and discusses both the methodological problems that were encountered with the research where the actual metrics suggested themselves became apparently inappropriate or invalid for reasons discussed. Although some of these metrics bought up problems of applicability, many had no problems at-all however and thus in the interests of conciseness, shall not be re-examined.

The second section is a critique of social network analysis' applicability to the field of innovation studies. It covers both the applicability and appropriability of the different metrics used for assessment of different functionalities as well as their overall strengths, weaknesses and insightfulness of application to the field. Unlike established metrics, since all metrics and their applicability are 'new', they shall all be discussed within this chapter.

9.2 Overview of Established Metric Applicability, Strengths and Weaknesses

The established metrics used within this research are clearly invaluable and key to the understanding of activities occurring within the wave energy sector. They have formed the base from which an insight into the disaggregated functionality and overall health of the system could be assessed.

A key critique of the innovation systems analysis approach however has been its conceptual diffuseness (Edquist, 2005) and this has certainly been shown to be the case within the research work. This has been especially true in terms of application and operation of analysis throughout the study in which established methods for data gathering or validation of proxy indicators have been left if not wholly undefined then certainly with a broad scope for interpretation in application. This is true even within established documentation for data gathering of innovation indicators such as the OECD's Oslo and Frascati manuals which suggest which data represents which activity (e.g. FTE employees represent employment) but often fall short on detailing (e.g. when assessing the number of FTE employees within the sector; metrics become less insightful when omitting, the *length* of employment creation, detailing on whether figures include direct and/or indirect employment), (OECD, 2005, OECD, 2002).

These 'weaknesses' however could in many ways also be interpreted as a flexibility that is required for a model of analysis that is intended to fit a range of systems in different states of maturities and therefore levels of *knowledge uncertainty* that are simply impossible to compare with like-for-like metrics.

Given the early stage of maturity apparent within the UK wave energy sector, this *knowledge uncertainty* is even more ubiquitous since many codifiable metrics, such as SIC codes, bibliometrics or learning rates (when no significant deployment has occurred) let alone more tacit ones such as indicators of *legitimacy* and *internal influence* become either extremely hard to obtain or in some cases almost too broadly open to interpretation to give significant insight.

Likewise, many of the functionality proxy indicators would themselves be extremely hard to collate if they were undertaken from a 'first to investigate' starting position. Proxy's such 'investor confidence', 'sectoral resource investment' and other indicators would not themselves be possible to obtain 'first hand' without a great deal more research capital being spent. (i.e. harder work for the person conducting the TIS analysis.)

Ironically, these indicators themselves may only become available once the sector is mature (or legitimate) enough for policy makers, investors, pro-renewable support agencies and other stakeholders with a sector wide perspective/interest to mobilise the resources required to investigate them. This itself leads to an increasing of legitimacy as knowledge about the pro's and con's of the sector allows for greater confidence, (and thus legitimacy) then would otherwise be available.

In this respect, when a system is so early in its emergence, the innovation systems approach is close to the methodological limits of its framework, essentially between the meso-economic analysis of the emerging system (in which broader trends of functionality can be meaningfully quantified) and the micro interactions of singular businesses, where the interactions and outcomes of events produce (among other things) informal, 'social capital' building outcomes, the value of which is hard to quantify and assess. (This was itself clearly one of the initial arguments for the investigation of application for social network analysis).

Unfortunately, it is therefore apparent that a certain level of both tacit knowledge of the sector and its operational 'style' (i.e. is it patent heavy and carrying out 'formal' methods of experimentation, does it have enough legitimacy to even have clearly understood indicators established such as policy statements and perceptions), as well as a knowledge of the tools and metrics available for an innovation systems analysis are required before an innovation analysis itself can be conducted with any validity.

Building on this however, after background and contextual research has been conducted, it is clear that many metrics for different functionalities *do* provide differing levels of insight at different levels of system scales, or (more apparently), different stages of system maturity. Therefore, for many aspects of the wave energy sectors analysis, established indicators have proved to show extremely useful insight. These are discussed (by functionality) further below.

9.3 Established Metrics Findings

9.3.1 Resource Mobilisation

Resource mobilisation metrics brake down into two broad areas, financial resource mobilisation and human/skills resource mobilisation. These metrics are discussed individually as well as their applicability to the wave energy sector below:

9.3.1a Financial Resource Mobilisation

Fiscal resources are split into those that originate from the public sector, (i.e. central government/EU etc.) and those that originate privately (i.e. VC, angle investment etc.) although many companies publicise when contracted deals are made, acquiring information on public spending was generally far easier to attain (due to freedom of information laws) than information on private finance. Even then however, the ever changing landscape of funding grants, bodies and conditionality attached to financial support made collection of accurate financial information a challenging task. When the building of test centres is included within the data, the estimated financial spending on marine energy (inclusive of tidal) is around

£235m over the past decade. This is far higher than IEA data estimations (See the Resource Mobilisation section of the Established Findings chapter, section 6.2.1)(IEA, 2010).

A key findings regarding financial resource mobilisation as an indicators is that the method by which finance is provided (or 'acquired' into the sector) has as much, if not more of an influence upon sectoral development as the amount of financial resource available. Some of the many aspects that shape financial resource mobilisation are listed below:

- The motivation of the financier: This is the largest single factor affecting metrics of financial input since the 'efficacy' of spend within the sector itself (and in terms of a functional analysis) is only relative to the success of the policy ambition (or assessment criteria) which motivated it in the first place. That is to say, if creating regional employment is the key ambition of a financial instrument, the metric of 'success' for that policy is the number for FTE employees (over a set timeframe) within a region rather than (for example) tonnes of CO_2 mitigated. This may seem obvious however when translated into a functionality analysis, the funding motivation directly relates to which functionality/proxy is being enabled/supported. Although these motivations/forms of funding are not always exclusive to one functionality support (e.g. funding to bring a technology developers device to a higher TRL will be both knowledge generating and no doubt promote entrepreneurial experimentation) a quick explanatory of examples is provided below:

    - Resource Mobilisation: Leverage funding, usually applied to almost all public spending into the private sector as a conditionality of EU state aid rules.
    - Influence upon the Direction of Search: funding for road-mapping and methods for sector/stakeholder-articulation of demands (i.e. questionnaires, advisory bodies etc.)
    - Materialisation: Direct funding for capacity building, grid infrastructure and manufacturing plant within a less developed sector, acceleration of technology readiness level (aligned with knowledge generation and entrepreneurial experimentation)
    - Knowledge Generation: funding for fundamental (and also in most cases, applied) research such as methods for resource assessment or device power extraction.

- Legitimacy: Depending upon which form of legitimacy; of the technology or sector, providing funding for the creation of standards, best practices and certification bodies (such as test centres) or conferences, policy statements and promotional material respectively.
- Market Formation: Overall system building comprised of other functionality attainments. Supported more through high 'market pull' funding however, otherwise not directly fundable.
- Development of Positive Externalities: Encouragement of spin-in/spin-out innovation such as patent pooling or funding to promote sector 'buy-in' (adaptation) from (key enablers of) other sectors.
- Entrepreneurial Experimentation: Funding applied R&D, research capacity improvement such as test facilities and (as with development of positive externality) funding to promote sector 'buy-in'/new entrants.

- The levels of risk associated with the funding: Different routes to access for funding hold clearly different levels of associated risk. The most common examples of this include the difference between revenue support and grants or between tradable certificates (such as ROCs & LECs) and guaranteed revenue per KWh or MWh generation (such as FITs or NER300 funding) where in both cases the latter clearly has a lower profile of risk attached. Understandably, risk must be managed by public sector investors into the system as much as for those acting within it however a funding policy which is heavily risk adverse (such as the ROC mechanism) will either require higher support levels for equal results or simply be too risky for the technology to emerge (as was the case with a 5 ROC support regime).
- The ownership of funded outcomes: This is an especially sensitive aspect when dealing with collaborative projects and the transference from fundamental research knowledge to applied commercial knowledge (see Overview Findings on Knowledge Generation section (9.3.5) below for more discussion on this). Clearly with public funding there is often an agenda to make research findings public (as with much university research) however this may not always be the case.
- Funding conditionality, legitimacy and the search heuristics of the sector: All public funding has to be 'offered' to someone working with the sector whether through prohibitive aspects of a tender (such as prohibitive conditionality for skill sets or company turn-over to ensure large companies are involved) or

through directly focussing the funding at a particular stakeholder type (i.e. device developers etc.). Although government claims not to 'pick-winners', it is impossible in practice *not* to filter what is perceived to be the winners out based on the criteria required for tender success. For example, by deciding that the lions-share of public deployment funding should go to device developers that already had three months continuous operational time, the MRDF was effectively attempting to 'pull out' sector fore-runners. This is discussed further in section 10.2.3a of the System Discussion Chapter, (Chapter 10)

9.3.1b Human Resource Mobilisation

Unlike financial resource mobilisation, there was very little solid data previously published on current FTE employees with the sector however through the interview process as well as results formatting, an estimated 650 FTE direct employees (425 in engineering, 94 in marketing/sales, 106 in environmental and planning activities and 25 in administrative roles), was obtained, many within academic and research areas. As a result of the diversity of direct employment locations (e.g. universities, public sector etc.) indirect employment statistics (through matrix multipliers) have not been calculated. The study also found around 127 postgraduate students are currently researching wave energy, a significant number of which are located at the University of Edinburgh.

All of the obtained employment data acquired was for future employment expectation and as outlined by Dalton *et al*., much of the data provided within these employment metrics often failed to articulate the methodology and detail within them required to provide actual value to the figures (Dalton and Lewis, 2011).

Detailing often found missing from employment statistics included:

- Time domain of employment: This was the most common problem with employment statistics. The nature of wave energy technologies, (as with most large construction projects) means that the profile of employment is clearly very front-heavy when construction and deployment is underway, trailing off to an operation and maintenance staff level and then rising slightly for decommissioning. Most statistics did not include any breakdown of the timeframe or profile of the employment and thus missed an important factor of the data. (e.g. whether the employment is 100 FTE jobs for 2 years or for 10 years).

- Inclusion or not of indirect jobs: This is also an important aspect. As found in preliminary work by Bahaj, for the wave energy sector there are expected to be 3 indirect jobs created for every 6.5 direct jobs (Bahaj and Batten, 2005). The inclusion or not of this distinction therefore alters the resulting statistics by almost 50%.
- Geographic dimensions: Assuming employment statistics are given in a job/MW/yr, there needs to be some identification as to whether this applies likewise to export MW capacity since export MWs will require less national employment then domestically installed MWs.

Additionally, since all future employment statistics were based upon a future per-MW installed capacity, the wide variation in deployment expectation, (compounded with potentially different estimation methodologies) resulted in large variations in assessment.

9.3.2 Influence upon the Direction of Search

The influence upon the direction of search was sub divided into three specific sections. Since internal and investor influences were established through direct questionnaires (albeit that the investor questionnaire was conducted as separate research by Kreab & Gavin) there was no methodological problems with using them as direct proxy indicators, Government influence however proved somewhat less straightforward.

Although government roadmaps and deployment expectation proved both easy to find and reasonably informative, one interesting disparity was the lack of association and cohesion between different departments, devolved administrations and other prominent (public and non-public) bodies such as trade associations and NDPBs. This was also found to be the case within the same departmental bodies over different periods of time. One of clearest examples of this is the shift in UK deployment expectation DECC showed between its March 2010 Marine Energy Action Plan which suggested a broad expectation of between 1-2GW of marine energy by 2020, and the July 2011 UK Renewable Energy Roadmap which made a central range suggestion of up to 300MW by 2020 (DECC, 2010b, DECC, 2011b). Although some adjustment of expectation would be expected, this magnitude of variation severely devalues the credibility of public sector reports. These figures become even more inconsistent when observed against the devolved administrations ambitions of 0.5<2GW (with a mid range level of 1GW) within Scotland by 2020 and 4GW within Wales by 2025 (Scottish Government, 2010b, Welsh Assembly Government, 2010).

9.3.3 Materialisation

Due to the immaturity of the sector, gaining details on the levels of capacity that had been deployed was straightforward, (1.31MW nationally as of June 2011). Levels of TRL were also acquired through direct questioning and thus accessible and reliable. Even with an increasing of maturity for the technology and higher deployment rates, these statistics are relatively easy to acquire on a national level however as technology export/import becomes more prevalent (especially international sales of UK technology), system boundaries and levels of technology deployment would have to be acquired through each manufacturer rather than published national statistics.

9.3.4 Knowledge Generation

Knowledge generation statistics came from patents, learning curves, bibliometrics and R&D expenditure. Of these, only publicly available R&D expenditure statistics were relatively straightforward in interpretation and easy to access although according to many interviewees, many of the conditionalities of R&D funding proved to be more important than the actual level of expenditure (as outlined in the resource mobilisation section 9.3.1a above). Other indicators are discussed further below.

9.3.4a Patents

Patents are possibly the single most strongly recognised indicator of innovation. Although there are many limitations to the interpretation and application of patents (as outlined within the Introduction chapter section 1.3.1), there are also many narrative insights that can be found from assessing patents.

Patents show a picture that is clearly not in-line with perceptions of legitimacy with regards to technology types. However they were a good indicator of innovation, (using TRL as the fixed variable indicator of innovativeness) but *only* for device developers or *applied commercial knowledge* which is itself only one aspect of innovative knowledge creation (see section 9.3.5 for a further expansion of this). They are also not representative of stakeholders who patent very few of their technology innovations as can be seen from the findings of question 1e shown in Figure 109 below.

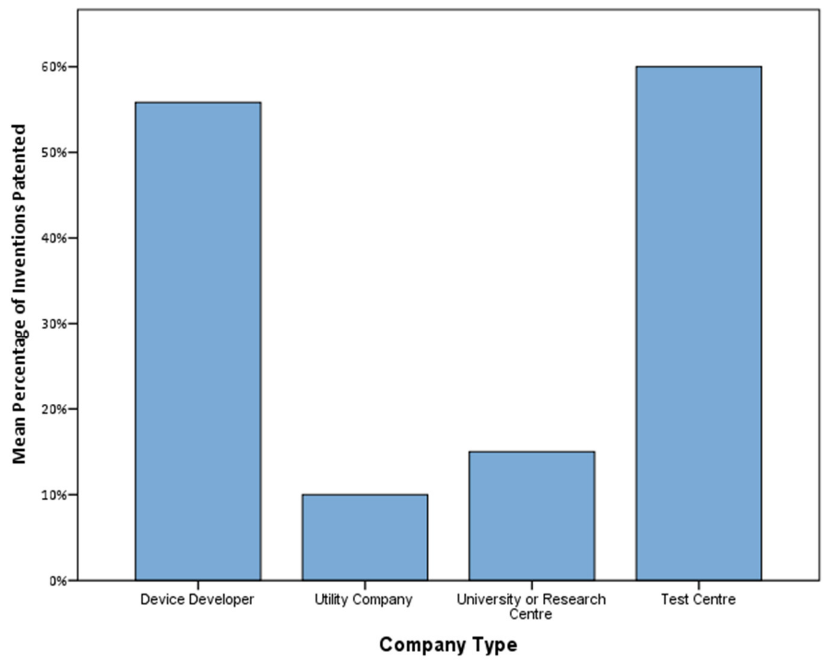


Figure 109 Estimates on Number of Inventions Patented

Patents also show a disparity between the UK and the rest of the world. The extra ratio of non-fixed patents as well as the lower % of overtoppers is reflected by the quantity of active device developers within the UK sector.

One final aspect of patenting that also became apparent through the research was that the application of patents for the exclusivity of technology use varied depending upon the novelty of the concept being patented. Less radical innovations, (such as point absorber or OWC designs) tended to have higher numbers of patents focussing on sub-component level innovations, (such as power extraction elements) whereas more novel devices (such as attenuators) tended to have singular 'broad' patents that covered the entirety of the device.

9.3.4b Bibliometrics

Two primary methods were used to acquire information regarding the number of articles published by the sector. The first was through a bibliometric search of academic journals using various web searches, the latter was through direct discussions with university and research institutes. Each of these two methods holds different strengths and weaknesses. As discussed individually below:

Desk Based Search:

The advantages of the desk based search was that it provided citations from *all* publishing sources rather than simply those interviewed and therefore had a wider catchment of publishers. The desktop study was also carried out internationally since the publication knowledge search heuristics (i.e. where academics or others search for publications within their field) is international in scope rather than other knowledge generation indicators, such as learning/experience curves for example. The drawback of this search methodology however is that it is hard to assess what percentage of relevant publications one has found since publishers who are working within niche areas of the sector, (such as wave modelling or hydraulic power take off systems) may publish without reference to marine or wave energy technology. Desk based study therefore allows for a wider catchment of institutions however, a narrower catchment of publications. Although not conducted due to resource limitations within the study, citation analysis is an optional advantage of desk based studies.

Interview Based Studies:

Directly asking interviewees how many journal publications they had related to the sector held several advantages and disadvantages over desk based studies. For smaller institutes and those with well documented publication records, this method proved very much reliable since interviewees usually had publication lists available. For larger and more diverse institutes, (i.e. those who had departments working within more than one knowledge fields) this could prove problematic since no one stakeholder had a clear impression of the entire institutes publication record within the sector. To allow for some practicality of response, interviewees were asked to provide publication figures for the prior 3 years since any more than this time would again cause logistical complications for interviewees. The main advantage of this methodology is that a wider catchment of publications that were directly related to the sector but not potentially listed as such, (i.e. niche specialist) could be obtained however clearly the interview based findings provided a narrower catchment of institutions then that allowed for by desk based.

For several institutions (under instruction from the interviewee) one final method of bibliometric assessment undertaken was to look on the research institutes website for all publication listings. This clearly provided a more accurate figure than could be obtained through discussion and is something of a synthesis of the above two techniques however was only valid on an institute by institute bases.

9.3.4c Costs Estimations/Learning Curves

There was a very wide range of discrepancy between most learning, experience and cost curves due to the heterogeneous nature of the technology, confidence in initial cost estimations and assumptions on learning rates (i.e. percentage decrease per doubling of capacity). One thing that may have assisted was details on how learning curves were derived including estimates of the initial costs of deployment and the learning rate. Many learning curves also assumed national learning rates rather than international and did not account for the potential learning cost reductions that would be found as a result of overseas sales which would be expected to have some, (if not quite as high), national learning attached.

9.3.5 Overview Findings on Knowledge Generation

A general picture emerged from the responses to question 1(c); (How much do you believe that academic research contributes to the value of knowledge generated within the wave energy sector?) that overall, academia has played an important role, with almost all respondents believing that the contribution was between moderate and most of the value (See Figure 110 below). It became apparent however was that respondents perceived not only the level of knowledge contributed towards the sector as having changed, but also very much the *type* of knowledge.

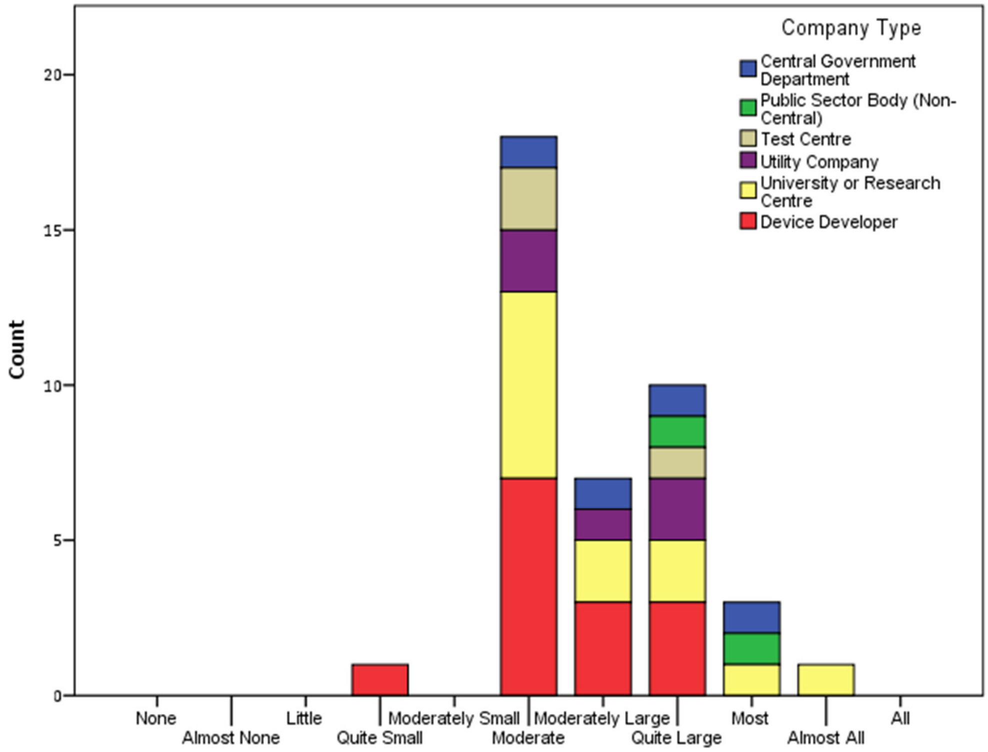


Figure 110: Perceived Level of Knowledge Contribution towards the Wave Energy Sector from Academia

Three broad types of knowledge were identified through extended discussions emerging from question 1(c) as well as others based on knowledge generation:

- The first type is that arising inherently as a result of previous experience of working in the physical marine environment. This included the vast amount of *generic* (i.e. non-device specific) *complex knowledge* that is required to operate and extract energy within the marine environmental context. This included an understanding of wave modelling, environmental responses, material properties and other fields that (although technical in nature), were not of directly commercial application. Much of the initial research conducted during the 70s and 80s in the early stages of the sector's emergence was focussed on these challenges and although this focus has shifted somewhat over the last decade as many of the underlying mechanics have become better understood, there is still a great

> "As we understand more, it's easier to pin down the specifics and tailor them more towards emerging technologies. I would say there's been a shift towards specific key aspects that affect the possibility of getting the consents that are required."
>
> Marine Management Organisation

deal of academic research that is focussed on this type of knowledge generation and problem solving. This generic technical knowledge can be codified and quantified through publications; however it holds tacit aspects, often embedded within the skill sets and competencies of a university, research or test centre. Serious fundamental gaps still exist in the generic complex knowledge base, such as long term environmental impacts of wave energy extraction and energy prediction where current modelling tools will only become validated once suitable experimental longitudinal data exists. This form of knowledge can be considered as 'free utility' to the sector in that it may have low commercial value (i.e. low levels of appropriability and thus easily copied or repeated) however it underpins the overall knowledge base within the sector.

- The second form of knowledge identified relates to that specific to the *applied technical knowledge* embedded within wave energy devices (e.g. through patents, software and manufacturing techniques) or within the commercial company (e.g. in the form of manufacturing and deployment competencies). This form of knowledge tended to hold higher levels of commercial sensitivity due to its value to device developers and other commercially driven stakeholders (such as investors and utilities). Most applied knowledge within the sector was built upon the understanding and application of *generic knowledge* available in that an intrinsic understanding is required of the resource as well as its effect and affect upon a specific device in order to create valuable applied knowledge of the device itself. Within the last decade, most respondents believed that this form of knowledge has becoming ever-more present and important to the commercialisation process (hence the high levels of patents per M$/R&D spend shown within GB Patent Statistics Section (6.5.1c) of Chapter 6, the Established Findings). Typically, respondents (including some universities) believed that this was the domain of private companies such as device developers and not universities who were better suited, and had a 'track record' of working within generic complex knowledge and thus providing consultancy in such matters or even in assisting in developing generic knowledge in commercial application (such as Edinburgh Designs Ltd who commercially consult on and build wave test tanks). This is interesting as it has serious implications for shaping the type of interactions that device developers and universities can collaborate on. Having a well defined scope of work where commercially sensitive applied knowledge is held by device developers while the generic complex knowledge interface, (i.e. the resource measurements or standardised tests) can be conducted by universities. The overlapping stakeholder type identified primarily by device developers within this framework was considered to be test centres where high level of commercial awareness and applied knowledge were required for pre-commercial testing and was considered to be within their remit of operation. A few universities proved to be the exception and worked closely with device developers on commercially sensitive elements of their design. These relationships and the embedded trust had in almost all cases been a result of the development company itself spinning out from the university in the first place.

- Finally, the third form of knowledge relates to *institutional knowledge* in the form of regulatory alignment, support mechanisms, environmental monitoring requirements and standards for testing and reporting of devices. This knowledge is born from a synthesis of the prior two forms of knowledge, stakeholder engagement and the wider institutional environment for the purpose of standardising and aligning the sector with overall societal requirements (such as health and safety, fiscal equality or grid parity). This form of knowledge is effectively created to build a more stable operating environment for stakeholders, reduce risk and legitimise the sector, thus lowering the overall cost of business. It is clearly born out of efforts within the public sector and key rule making institutes (such as the Crown Estate and statutory consultees).

Table below summarises the findings of these knowledge types that were identified within the sector and their general characteristics of operation:

Name	Generic Technical	Applied Technical	Regulatory/Institutional
Description of Knowledge Type	Generic multidiscipline knowledge about the environment, resource and theory that underpins the sector	Commercially sensitive knowledge, specifically that related to the device	Synthesised multidiscipline knowledge allowing codifiable 'framework' for interaction
Example of Knowledge Type	Resource predictability and modelling, physical and biological environment modelling and monitoring	Manufacturing/operation and maintenance of devices affect and effect of device upon environment	Fiscal support policies, Standard testing procedures and environmental reporting requirements
Generator of Knowledge Type	Universities Test centres (Specific public sector bodies)	Device developers Test centres	Public sector governing and regulatory bodies
General Form of Knowledge Type	Publications Graduates Public reports	Patents Employees Device numbers	Regulations Rules Standards
Stage of Technical Maturity	Early-Mid	Mid-Late	Late

Table 77: Different Knowledge Types and their Characteristics Presented within the Wave Energy Sector

What respondents suggested through discussions expanded from question 1(c) was that during the initial stages of industry development (from the 1970s until roughly the 1990s), much of the work conducted was fundamental-science based questions focussing on assessing the resource potential, or assessing environmental scope of works and methods of power extraction. During the last decade however the focus has shifted as many of these initial problems have become understood and resolved. As such research has become increasingly device specific in focus and thus there has been an increased focus on both government supporting device developers directly through grant funding (rather than universities) and these device developers then contracting research when needed from universities directly. Alongside this current push for commercialisation has been a requirement for institutional alignment and reform such as with grid connectivity regulations, revenue based funding support systems (e.g. the RO), and marine spatial planning. There was also some acknowledgement that the regulatory and institutional framework for marine energy has been helped enormously by the earlier development of offshore wind which has provided a certain amount of free utility in this respect through the current focus on marine spatial planning and offshore electrical grid development (see development of positive externalities section of this chapter 9.3.8). This chronological focus of knowledge type is summarised in Table 78 below.

+ = Weighting	Rough Period	Generic Technical	Applied Technical	Regulatory/ Institutional
R&D	70s/80/90s	+++	+	+
Demonstration	00s	+++	++	++
Pre-Commercial	10s	++	+++	+++

Table 78: Shifting Focus of Knowledge Generation within the Wave Energy Sector over Time

The learning opportunities between these forms of knowledge types are of key importance since they represent the key forms of stakeholder interaction that occur within the system. As device developers perceive their applied knowledge to be commercially sensitive, there is a belief that working with universities can only be done in a setting that does not compromise their intellectual property. Therefore joint collaborations can occur in situations where the university either provides generic complex knowledge input to a device developer's applied technical problem (e.g. wave measurement data being provided to a developer to model power output from a device), or receives an applied technical output from a developer for application in a more generic model within the university (e.g. power output measures fed into a grid modelling simulation for example). There is a higher likelihood for a confidentiality clause being required with the latter since the applied data is being disseminated from the device developer. These interactions occur also between device developers and government, where government clearly requires information on device performance characteristics from companies (i.e. applied knowledge) in order to synthesise this into institutional knowledge.

A diagrammatic explanation of these knowledge types and examples of learning opportunity can be seen in Figure 111 below.

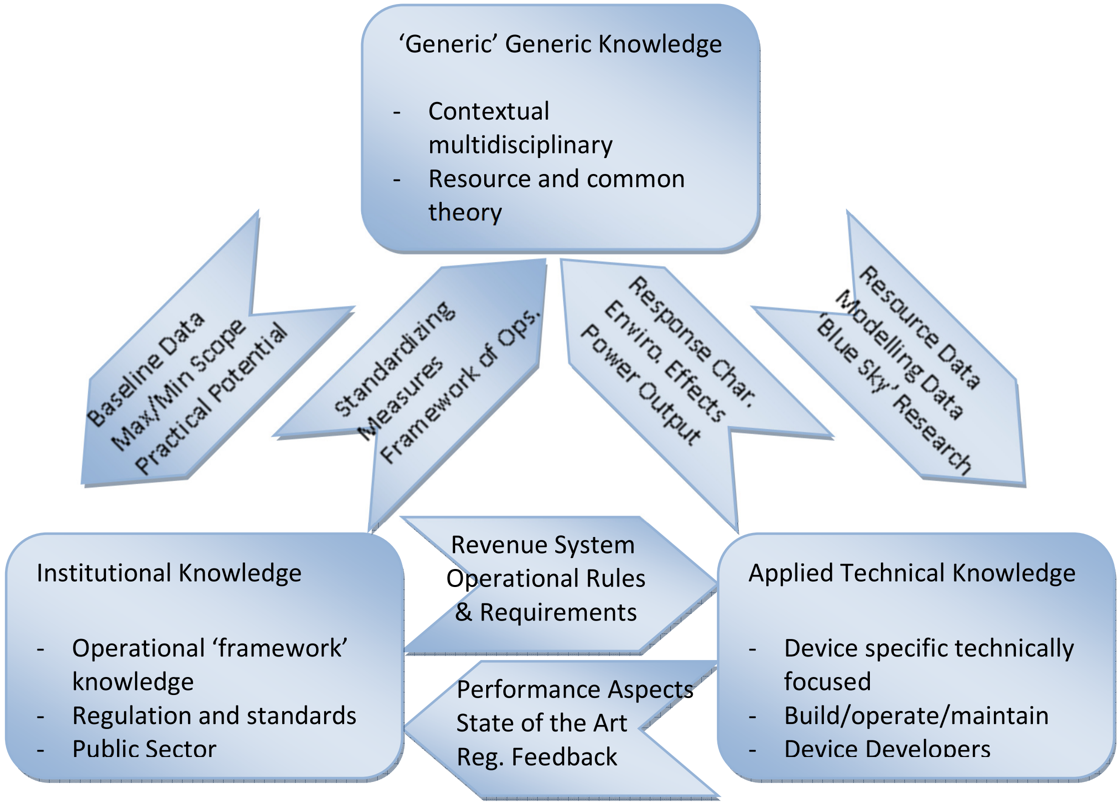


Figure 111: Diagram of Key Knowledge Types and Example Cross Learning Opportunities

It should be mentioned that these three actor groupings are the same, (i.e. academia, industry and government) as those within the triple helix model of innovation outlined by Leydesdorff, (Leydesdorff, 2000) however, the relational model identified above is notably different. Primarily because the triple helix model of innovation identifies a wider conceptual framework of innovation 'lock-in' and 'lock-out' without discussing the nature of the knowledge forms that are being both exchanged with and generated (through interactive learning) within the different stakeholder groups. This knowledge type and interactive learning aspect between different stakeholders has (certainly within the wave energy sector) wider implications for understanding the nature and potential of collaborative innovation and the limitations/opportunities therein.

As the generic complex epistemic networks had less commercial application, there has historically been a higher level of interaction among its principal actors, (universities) which has resulted in a high level of established technical and environmental academic networks within the sector. These denser knowledge sharing networks are desirable from a systemic perspective for 'generic' (i.e. non-device specific) complex problem solving, (as discussed within the Literature Review, SNA within Innovation Studies Section, 2.4.4). As the sector has matured, the networks have expand and become more sparse while the focus has shifted towards more commercially focussed, applied technical knowledge with the most embedded early stage actors (e.g. Universities of Edinburgh and Manchester etc.) becoming more prominent 'consultants' within the new regime.

This research has found that the type of network depends not only upon aspects identified by Ahuja, (i.e. the value of the knowledge and the cost of obtaining it) but also, building on Walker's observations regarding the 'type' of network that is undertaking the research, (i.e. collaborative or market competitive) it has been found more broadly, that the type of knowledge and learning occurring is crucial (Ahuja, 2000, Walker *et al.*, 1997).

9.3.6 Legitimacy

There were several metrics for legitimacy used within the study: Public perception of legitimacy; Government representation of legitimacy; Investor perception of legitimacy, internal perception of legitimacy and legitimacy of the technology. Since the methodology used for gaining insights into each was different, applicability of these methods/metrics are discussed individually below.

9.3.6a Public Perception of Legitimacy

As a metric, public perception of legitimacy in practice means polling people for their opinions. This approach (and indeed any sub group such as 'investor' or 'utility' perspective on legitimacy) is fairly straightforward methodologically. The potential challenge occurs when ensuring that a significant enough level of representation has been polled to validate the findings. Clearly, the scale of this study was not wide enough to encompass a mass polling of the general public however DECC had conducted prior opinion polls on public perceptions of technology that made an assessment possible (GfK NOP Social Research, 2009, GfK NOP Social Research, 2008, GfK NOP Social Research, 2007, GfK NOP Social Research, 2006, TNS, 2003).

As discussed in section 9.2, if the technology legitimacy was not seen as high enough, (i.e. the technology was not considered worthy of the investigation), then even obtaining metrics on public legitimacy would have proved un-practical.

9.3.6b Government Representation of Legitimacy

Government representation of legitimacy was also fairly easy to obtain however as mentioned in the Influence Upon the Direction of Search section above (9.3.2), there was a great deal of variation in a wide range of public representations of legitimacy. Targets and expectations for both deployment, employment and economic benefits varied substantially between key government bodies as well as devolved administrations and perhaps more insightful as a metric of legitimacy was industry response to government statements, (such as Renewable UK's critic of the MEAP (RenewableUK, 2010b)). These provide a more pragmatic and rationale perspective of the current industries status.

9.3.6c Investor Perception of Legitimacy

Although several utility investment companies were interviewed within the research, as with public perceptions of legitimacy, investor perceptions of legitimacy were made possible only due to prior-work commissioned by DECC and undertaken by Kreab Gavin Anderson (Kreab Gavin Anderson, 2010). This study proved extremely insightful however as with public perceptions of legitimacy, would not have been possible to obtain had the legitimacy of the sector itself not have reached a critical point in the eyes of public sector commissioners.

9.3.6d Internal Perception of Legitimacy

An internal perception of legitimacy from active stakeholders within the sector was fairly easy to obtain through the interview process. All interviewees (except device developers and central government) were asked to rate how commercially viable they believed the different technology sub-groups were from 1 to 10. Aggregated, of the 28 respondents to this question, the average values for technologies legitimacy is plotted against both the average TRL values (for all 14 device developers interviewed) as well as the overall number of UK device developers within each technology type sub-category (23 overall) in Figure 112 below.

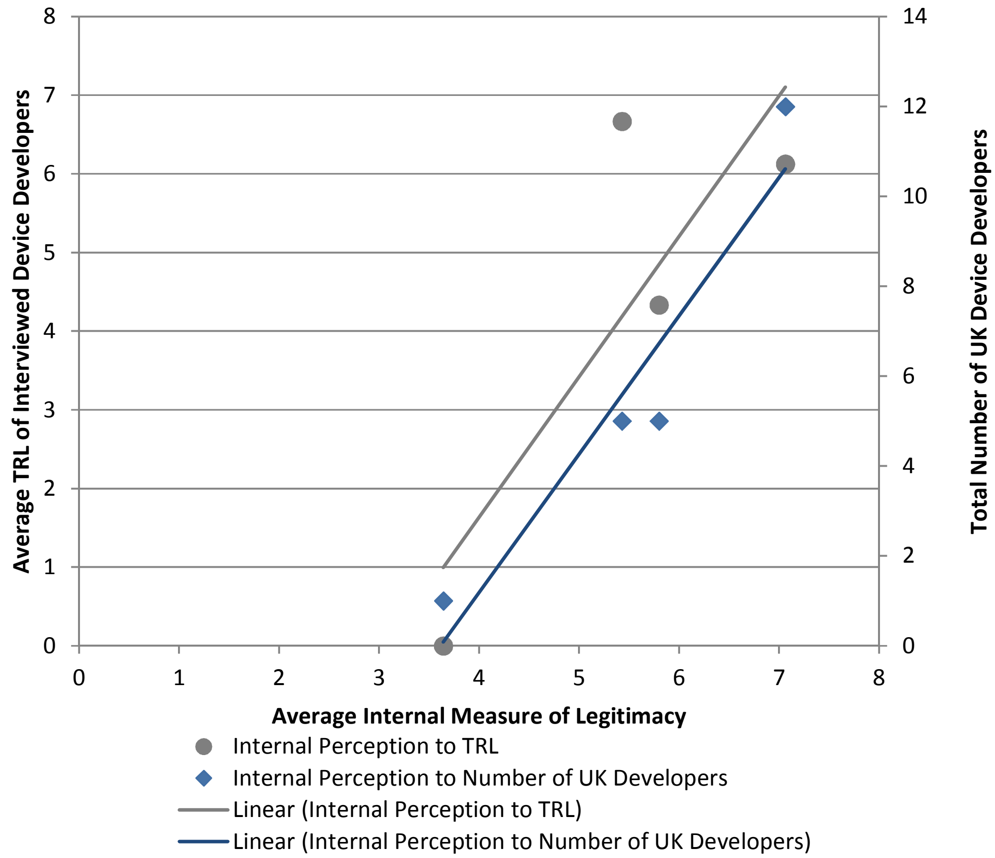


Figure 112[1]: Internal Legitimacy Perception Compared to TRL and Total number of Device Developers

As can be seen, the total number of device developers present within the UK of each sub-category type is a much closer correlation with stakeholder perceptions of technology legitimacy then the average TRL value of all interviewees however it is unfortunate that the remaining device developers, (mostly of low level TRL) could not be included to verify that it is number, (rather than technology maturity) of device developers that is the most prevalent indicator of legitimacy. In all likelihood however, it would be combination of both factors.

9.3.6e Legitimacy of the Technology

Legitimacy of technology is covered in more depth within the internal perceptions of technology section above (9.3.6d) however there is surprisingly little published data on perceptions of the most promising technology sub-category within the wave energy sector which is clearly a sign of the lack of current technology convergence. Internal interviewee data

[1] Overtopper TRL value has been assigned as 0 however it should be noted that there are no overtopping type developers currently operating within the UK therefore this value has been assigned to indicate the lowest level of technology readiness for diagrammatic clarity.

as well as TRL data proved most insightful when assessing which technology sub-groups had the highest technical legitimacy.

9.3.7 Market Formation

The wave energy sector is clearly a ‘nursing’ stage market, an understanding of which is itself one of the (easy to identify) indicators of market formation within the analysis. The two other forms of prox for market formation were the formation of networks and the stakeholder perception of market requirements discussed below.

9.3.7a Formation of Networks

Findings from the formation of networks research showed that there were four network types: Industrial representation, public research, academic led and regional economic networks. Each network type has its own characteristics of purpose, size and geographic boundary. Scotland also clearly has far higher level of established network activity. This finding leads to the potential for stronger cross-network learning for *like-category* networks which could help to reduce overall learning and transaction costs (through best practice operations) as well as ensuring optimum efficiency of network activity (such as joint lobbying/research programmes etc.).

Collecting this data was relatively labour intensive as a desk based study but provided no major methodological complexities.

9.3.7b Primary Study findings

The primary interviews sought to assess what stakeholders perceived as the major bottlenecks within the commercialisation process and what they perceived device developers needed to do to attract investment. The main methodology for this was fairly straightforward as part of the primary interview process and the findings were clearly insightful. For example, noting that utility companies valued a proven track record above cost reduction shows their willingness to accept higher cost, lower risk projects as a preference, so long as the subsidy level still supported the required return on investment.

Also insightful was that most device developers (of all TRL stages) were in communication directly with utility or project development companies regarding their expected product requirements.

9.3.8 Development of Positive Externalities

Due to the highly qualitative and narrative nature of this function, primary metrics per se were much harder to quantify then many other functions. A wider understanding of related sectors and their interplay with the system was key to assessing this functionality and was established through three main actions:

- Understanding the historic emergence of the system: This allowed for the creation of a systemic 'family tree' of the sectors emergence, (i.e. from its niche development/genesis, understanding the background of the first investigators or entrepreneurial experimenters in the sector provides a historical picture of the system's growth).
- Understanding the current status of the market/sector: As other sectors have emerged alongside the wave energy sector (such as offshore wind), complementarities in deployment environments, skills, market actors etc. emerge which have spill-over benefits to each other, often from the more mature system to the less mature one (although this may not always be the case).
- Understanding of the technology: Primarily, through some understanding of the type of technology that is involved within the system, spill-over of knowledge and competencies can occur within sub-components of the devices (such as power take-off, mooring systems etc.). For example, the development of a bulge wave collecting distensible rubber tube system by Checkmate Sea Energy; the Anaconda was only made possible through the parent company's (Checkmate Group) prior experience of specialist rubber skirts and seals used for hovercrafts. Likewise, many of the device designs and procedures (such as environmental assessments), used within the sector come from (or are undertaken by) stakeholders with prior experience in the oil and gas or offshore wind industries.

The two subsections below examine the operational appropriability of previously cited metrics that should be assessed when examining the development of positive externalities (Bergek *et al.*, 2008a, Bergek *et al.*, 2008b):

9.3.8a Functionality across Sectors

As mentioned in section 9.3.8, much of the functionality across sections relies heavily on a somewhat tacit knowledge of the history, context and technology of the sector to create any form of insightful examination. This understanding was assisted as much through the background review of the sector (Chapter 3) as the primary research stage itself.

It is clear that there has been and currently is a great deal of positive development between the tidal industry, which is often seen as the 'same industry' under the umbrella 'marine renewable energy' sector from a policy support perspective. This is as a result of similar sector maturity despite very different technological designs employed. More influential however is the offshore oil and gas industry and the currently great push for offshore wind within the UK which has had a strong influence upon the locality of regional networks and clusters, (such as Aberdeen), the companies involved (such as Xodus or Det Norske Veritas (DNV) from the oil and gas industry, or GL Garrad Hassan from the wind industry) and the subsequent formation of practices and standards that are often formed through the 'norms' of these sectors, (such as the, DNV standards).

Logistically therefore, although this "metric" was not conceptually complex, the findings themselves, (i.e. the interpretation of 'proxy indicators') proved more tacit, subjective and narrative making 'replicability' of study options low.

9.3.8b Other Key Measures

Despite its extra importance in immature sectors (Bergek *et al.*, 2008b) the lack of deployment within the sector has resulted in a lack of opportunity for intermediate goods to emerge within the supply chain or pooled labour at this scale which made metric identification extremely difficult. Several key public sector financed R&D programmes had been run to identify cost reduction opportunities within 'communalised' components (such as wet-mate connectors etc.) however these were limited in scale and were in themselves non-diffused inventions, (i.e. had been built as prototypes/R&D programmes). Nonetheless, until some scaling up of manufacturing occurs (i.e. more than singular prototype/demonstration units) the only conclusion that can be drawn is that there are currently no intermediate goods within the sector.

One thing that could be identified quite clearly was some levels of political power and influence that the sector and its advocates had. In this regard, Scotland clearly held marine renewable energy in general on a higher pedestal of support than the UK government.

9.3.9 Entrepreneurial Experimentation

Two key measures of entrepreneurial experimentation were used to assess the overall variety and scope of experimentation activity occurring. These are discussed in greater detail below:

9.3.9a New Entrants and Diversity of Activity

Initially SIC codes were gathered for all stakeholders to try and categorise stakeholder activity classifications (using SIC(92)). It became apparent however that there was very little coding continuity (i.e. multiple SIC codes were used for similar actor types such as device developers or energy companies) between actors and thus little generalised inferences could be drawn since there were too few SIC code groupings overall.

Although information from primary interviews could ascertain the entry time of actors into the network, this process clearly excluded market exits (since they were not interviewed) and thus could only give a generalised view of market entry/exit profiles.

Compiling an extensive list of device developers was valuable in that it showed some sense of international activity and which countries had the most entrepreneurial activity within the field. Although technically this assessment was 'outside' of the system boundary, it provided insight by allowing the UK's level of entrepreneurial activity to be placed within a wider context.

9.3.9b Tank Test Time

Tank test time, (gathered through the interview process with device developers) was considered by most respondents to be an unreliable metric given what could be expected to be the wide discrepancy between modelling validation conducted and access to capital/finance however having assessed the respondent answers, tank test time did actually correlate well with technical maturity of devices.

9.4 Overview of Social Network Analysis Applicability

The following section discusses the methodological applicability, strengths and weaknesses that were found when trying to introduce and use social network analysis as an assistive tool in the analysis of the wave energy sector innovation system. These issues cover the spectrum of functionalities for which SNA was used and can be broadly divided into methodological problems and strengths, (i.e. conceptual and theoretical complexities or opportunities that were found) and operational problems and strengths, (i.e. practical and in most situations case-specific problems that occurred during this analysis).

One of the methodological aspects (both problematic and opportunist) with many of the SNA metrics of analysis (such as clique analysis) related to the many alternative settings that had to be considered and applied to the analysis. For example, this could include: the type of epistemic network assessed, whether the network should be symmetrised or not, whether the particular analysis should be 'full network' or 'system actors only', which subgroup type analysis would be most insightful, what dichotomisation level would be most insightful, what clique step distance (n) would be appropriate and what the minimum clique size should be to be valid. This wide range of variables and others provided for a far greater scope for analysis however also required a far deeper understanding of the metrics and theory in order to ensure that the findings were still logically appropriate. For example; in many social science applications of network analysis, laws of transitivity within friend groups apply, (i.e. whereby if *a* knows/likes *b* and *b* knows/likes *c* then it is assumed that *a* should know or would like *c*). Within innovation theory however this does not seem logical since the nature of the relationships are practical, based on the requirements for a specific service or product. Although more intrinsic elements such as trust and legacy may exist between actors within companies, this does not imply a tacit 'friendship' in the same fashion as with individual social networks.

Another applicability observation from the network validation & national centrality metrics was that the system boundaries within the UK seemed appropriate (given the high levels of inter-actor communication in comparison to non-system actors who were far more referenced but generally at a far lower level). Likewise, although the national system boundary showed a high number of ‘non-system’ international actors, their overall intensity of interaction was on average far less. Nonetheless, one of the advantages of future iterative assessments is that actor inclusion could be done based upon levels of harmonic closeness or centrality within the network rather than on the initial triple helix model selection process of system actors.

The following two sections discuss an overview of strengths and weaknesses with the applicability of SNA within innovation systems analysis however function specific findings are described in the individual functionality sections following on from these.

9.4.1 Strengths of using Social Network Analysis within Innovation Systems

This section discusses the positive findings specifically related to the application of network analysis within the innovation system research that were found as a result of the primary research. These are all methodological findings since those ‘positive operational findings’ are (by definition) more relevant to the system findings discussed within the next chapter, System Discussion Section (Chapter 10).

As a tool, SNA overall proved extremely insightful into the activities of the emerging sector. Although interpretation must be done carefully, as an indicator of innovation, it treats all stakeholders universally and can thus allow comparison *between* different actor types, (unlike patents or bibliometrics with which (although it correlated well with), each of these metrics individually tend to be more prevalent within certain actor groups such as universities or high technology companies).

Additionally, prime movers, (or key contributing actors) can be easily identified throughout the process not only to help targeted support interventions but also so that in future iterations of analysis, external stakeholders can be identified and internalised within the system boundary. This can be done while those least contributing to the sector knowledge flows can be removed so as to ensure that the pay-off between, feasibility of workload and relevance of information can be optimised through each successive iteration.

Because the stages of an SNA analysis force the identification of a system boundary, it allows the researcher to re-assess the system boundary on follow-up iterations of the overall analysis based on feedback from the assessment of the first iteration. It effectively measures the validity of the analysis in that it tells the researcher if he/she is indeed looking at the core sources of knowledge and innovation generation. If, at the end of a ‘cycle’ of analysis, it becomes apparent that a large proportion of the knowledge gained is arriving from non-systemic actors of a certain category, (for example, international research programs or similar knowledge industries) and/or specific activity is not present within certain fields that were first expected, (such as component suppliers or test centres) then the boundaries of follow-up iterations for systems analysis can be modified so as to minimise the externalities to the systems and, (based on the resources of the researcher) maximise the efficacy of research inputs. On the inverse of this, the show of validity that SNA provides, (through a low level of knowledge in-flow externalities) allows policy makers for a region, country or specific technological field to understand what stakeholders and indeed what system functionalities are under *their* influence, what will be susceptible to political investment as well as what will not. This system validation tool is one that effectively relates to 'incorporating' the positive externalities of the alternative analysis to the systems inspection.

Another benefit of applying SNA is that it is possible to proportionally identify certain systemic elements and relationships such as Identifying levels of university/industry collaboration through collaborative knowledge flows between industry and university actors (as well as structural holes in a network analysis). This can allow policy makers to:

- Understand if there are knowledge gaps or overlaps within the system;
- Identify specific and valuable knowledge clusters (which can then be linked through effective policy initiatives to other actors);
- Identify core agencies or stakeholders that should either not be 'allowed' to fail or have redundant knowledge providers to the sector in case they do;
- Identify ineffective agencies who may be costing high amounts but whose work is not being assistive to the overall progression of the sector.

One of the problems of the methodology discussed within the Overview of Established Metric Applicability, Strengths and Weaknesses (Section 9.2 above) is that, with hardly any sales or diffusion of innovation having occurred, vital metrics, indicators and attributes for company success and thus sectoral growth (such as cost reduction curves, deployment rates etc) are still missing. In this situation, there is a strong case for SNA at very early stages of technical maturity. This 'applicability shift' of analysis from SNA to status-quo R&D indicators would occur as the market diffusion begins to occur.

The conceptual framework in which SNA may be most applicable for future analysis may therefore be 'underneath' the niche stages of a 'multi-level perspective' (MLP) innovation systems models such as Geel's Socio-Technical Systems where the direct 'fitting in' of the scaled network over the sector as what Geels describes as a niche, (and then into the ‘mainstream’ and ‘landscape’) could be more apparent than the TIS system (Geels, 2004). As such, scalability of analysis could be conducted in the following way:

Scale	Industrial Focus	MLP	Network Focus	Metric
Macro	Sector/Industry	Niche(s)	Whole Network	Density/average ties, inclusiveness, cohesion
Meso	Region/ Stakeholder Group	Sub-Niche	Sub Group	Group centrality, cohesion, homophily, super-node analysis
Micro	Individual Stakeholder	Sub-Niche	Individual Actor	Centrality (degrees/closeness/betweeness), effective size

The strengths of SNA that make it more appropriate for analysis within smaller emerging networks are several:

- It is easier to reach saturation of the sector as actors are not too dispersed (However clearly identification may become harder!)
- It allows an insight into not only the non-formal outputs/collaborations but the structure of the network growth itself.
- It is easy to validate the number of responses through the number of non-respondent actors and (as a stronger indicator) the number of weighted in-ties internal to and external to the system boundary.
- It provides comparable measures between different stakeholder types, (i.e. unis and device developers) where non would previously exist.

This directs other potential application settings for SNA such as where status-quo indicators of innovation are less applicable. Inclusive of niche and ‘sub-niche’ scales could be in developing countries where formalised metrics (e.g. patents, investment) may be much less valid or hard to obtain quantifiable indicators then in developed ones. Also within system of very low ‘technology’ sector goods (such as rural farming) where again, innovations may be more informal and bespoke. Finally, also in ultra-high technology public sector research bodies such as the military or other extremely R&D intensive sectors where again, more standard metrics of innovation may prove invalid.

The last notable positive finding regarding the application of SNA is that, as can be seen from Table 57 within the section 7.3.1 of the Additional Social Network Findings and Calculations Chapter, there is little (although some) variation between weighted and non-weighted in centrality scores within the network which suggests that in future application, a simpler form of assessment could be conducted allowing for either a binary relationship, (i.e. if a stakeholder interacts with another or not) or perhaps a more simple weighted system, (i.e. if a stakeholder has 'strong', 'weak' or 'no' interactions) without much loss of insight. The main cost of this approach would be that the resulting findings would be non-parametric, so although one could see that (for example) the University of Edinburgh was the most central of the technical actors, it would be harder to quantify just *how much* more central it is in comparison to other actors. One would still have data on how many actors referred to the most central actor, but not clearly, how important that interaction was.

9.4.2 Weaknesses & Methodological Problems

There were several complexities that were encountered during the additional SNA assessment and these fall again into operational or methodological issues. Most of the weaknesses or 'failings' tended to be operationally based rather than methodological, (although one could argue that the complexity/unrealistic level of respondent engagement, of operationalising the analysis itself was a methodological weakness as it resulted in a high level of operational difficulties.)

One of the most prominent complexities encountered was when interviewing larger organisation stakeholders with many employees, (such as universities or central government departments). Here, many were unsure of the entire portfolio of interactions that were occurring, especially as specific knowledge type interactions could be occurring within different departments, (i.e. environmental/planning interactions within a biology department while technical interactions occurred within the engineering department).

Additionally to this, when asked what interactions organisations were engaged in within the sector, some highly influential 'prime-mover' organisations, (such as RenewableUK and University of Edinburgh for example) would be engaged in 'market/fiscal' interactions that were non-company specific and related more to the operational policy mechanisms of the system itself, (such as consultation of funding mechanisms or planning procedures) which were thus somewhat different in nature to those highlighted by more standard market/fiscal interactions.

Finally, the last methodological concern behind the application on SNA within the study is that, as the industry matures from the predominantly R&D phase into an early build/deploy stage and wider levels of diffusion begins to occur, the number of system actors involved within a sector will go up to include; a higher number of 'primary actors' (in current system definition terms), more complex supply chains with more tiers, more international involvement and a far greater number of customers and other stakeholders. The practicality of applying SNA to innovation studies within the manner of this research is therefore limited to emerging and niche sectors where very little (if any) product diffusion has occurred.

From an operational standpoint, there were several minor also noteworthy complexities within the data gathering as follows:

- Several actors (Aquamarine Power and Heriot-Watt University) provided 'low/medium/high' responses to levels of interaction rather than 1<10. This was later translated into 2,5 and 8 respectively.
- The Crown Estate did not answer the collaboration question. As such, ties-out from the Crown Estate were assigned in parity both by strength and knowledge field with all ties-in (i.e. reciprocity was assumed for all relations with the Crown Estate).

Individual feedback about methodological metrics within the analysis are provided within the below section and are more specific for each functionality.

9.5 Social Network Analysis Metrics Findings

9.5.1 Influence upon the Direction of Search

The analysis of patent influence within the sector was conducted in two ways as described individually below:

9.5.1a Internal Technology Group Influence

The group patent analysis allowed for a broad overview of information by sub-category. Within this group analysis several methodologies were employed providing differing levels of insight.

Firstly, inclusiveness was assessed through an overall patent network assessment of isolates, sub-groups and the 'main set' (i.e. the main cohesive patent cluster).This showed some level of the cohesion within the patent sub-category search heuristic and allowed for an overview of the patent field.

Secondly, the historic trend of influence occurring within patent sub-groups was assessed using a visual analysis of patents over the last century. It was found that there was a spurt of wave energy patenting in the 1920s as well as high levels of patenting and cross-patenting influence from the 1980s. This assessment gave an interesting insight as to the level historic timeline of patent development within the UK but was lacking on hard metric figures.

How influential patent sub-groups were to other sub-groups was assessed through both supernode analysis and group centrality metrics. Although slightly different, these metrics both provided different insights of equal value (one accounts for the direct level of citations between group to group including multiple citations from/to single patents while the other showed the number of individual patents alone within a group that have had influence from the other group). Through this analysis it was found that among other things, fixed/semi-fixed devices had been most referenced of all wave energy sub-categories (having influenced 14% of all patents) however non-wave energy patents were referenced by 70% of all wave energy patents making them far more influential.

9.5.1b Individual Technology Search Heuristic

The second way in which patent analysis proved insightful was with regards to individual patent influences; it provided more detailed information on specific patents of high influence overall and from within sub-groups of patents through simple centrality metrics. Through this analysis it was discovered that several specific patents are clearly more influential even using different measures of influence, (discussed further within the Different Patent section of the System Discussion Chapter (section 10.2.1b) and have a strong historical influence upon technology formation.

Although both these methods of analysis allowed for an accurate assessment of technology and technology group influence through the various metrics of centrality, their limitation was in the fact that there was no immediate (or clearly obvious) method of accounting for; a) the commercial success of the specific patents (i.e. heavily influential patents may not have actually been commercially successful at all), b) the historic degradation of influence, (i.e. a patent from 50 years ago, despite being highly influential at the time, may now be based on obsolete technology or ideas). And c) Non-wave energy related patents that are relevant to the sector. This last point seeks to acknowledge business practices such as patent 'thicketing' as well as other methods by which companies may hide their commercially sensitive products while still protecting them by patents through mis-classifying them (e.g. as broader 'marine technology' patents for example). Although individual wave energy company system actors within the sector were searched for explicitly with the UK wave energy patent search, many other companies could well have hidden patents also. In this respect, it is perhaps more appropriate to use patent analysis to gain a broader understanding of the patent/technology influence landscape rather than looking at specific patents and specific technologies.

9.5.2 Knowledge Generation

The extended SNA knowledge generation section was fairly extensive and covered several types of analysis as well as several sub-groups of analysis based upon the primary actor network. These are discussed separately within the below sections.

9.5.2a Individual Stakeholder Knowledge Generation and Diffusion

Various centrality metrics were used for the individual stakeholders knowledge generation and diffusion however they were all based upon the latter, (i.e. knowledge diffusion) rather than that of knowledge generation itself which cannot be clearly linked to network analysis metrics. Itself, measures of in and out centrality are often thought of as 'influence' and 'prominence' which would mean, (as with patent metrics) that these centrality measures could quite reasonably have been placed under the 'Influence upon the Direction of Search' metric. Since however, interviewees were told specifically that the interaction indicator was itself a proxy for 'who they obtained their knowledge from' rather than 'who you are influenced by', it was decided to be more purist in interpretation and forego the SNA standard interpretation of in and out centrality as measures of 'prominence' and 'influence' (Bonacich, 1987, Hanneman and Riddle, 2005).

The different measures for individual centrality are described separately below:

Individual Stakeholder Degrees Centrality

The most basic and straight forward measure of centrality, un-weighted and weighted centrality measures for individual actors showed not only the most contributing actors individually bust also broader trends. Clear patterns were noticeable such as the high levels of representation from universities and public sector bodies within the technical and environmental/planning networks respectively as well as the overall lack of multiplexity between the different knowledge networks. From a methodological standpoint, the similarity between weighted and un-weighted measures suggested that for future studies, a simpler non-weighted response could be conducted with magnitude of contribution, (i.e. the parametric element) being lost.

Individual Stakeholder Network Contributions

Harmonic closeness results (with a dichotomisation level of 3) produce tables of ranking similar to the centrality measures, again with universities dominating the technical network while public funding bodies dominated the market network. Although insightful, the extra workload required to conduct this analysis proved somewhat less justifiable given the similarity of results to the centrality scores.

Betweeness centrality also proved insightful however here, the two most technically mature device developers came out with the highest betweeness centrality within two of the four epistemic networks. Some explanation for this is given within the section, (7.3.1b).

Individual Stakeholder Cohesion Density/ Average Tie Scores

One of the complexities of the density and connectivity metrics used within this analysis was the data manipulation required to account for non-respondent system actors, (i.e. giving weighted reciprocity) which was done as described in the Cohesion Density section (7.3.1c). Although this was a step-by-step logical method of data processing, this validation left a high number of permutations and combinations of choice and analysis, some of which were subjectively justifiable, (e.g. assuming non-reciprocity between system stakeholders who had referenced each other). Non-the less, certain patterns became apparent such as the fact that Scotland had a far higher level of density and contributory influence internally than England.

9.5.2b Sub Group Knowledge Generation and Diffusion

National subgroup analysis proved insightful in comparison between England and Scotland, as well as providing indication as to the amount of external, (cross-border and international) influences that was being provided to each country. Lack of respondents however within both Wales and Northern Ireland (or simply lack of an established network of actors working within the sector in these countries) meant that, it was impractical to make bold assumptions as to the interactive behaviour 'per stakeholder' within these countries, (since there was only one or two respondents).

Stakeholder subgroup metrics of centrality proved highly insightful and allowed for an assessment of many of the primary motivating questions (such as 'how much interaction is occurring between device developers and universities). It also showed surprising patterns such as the high level of technical homogeneity among university stakeholders and that device developers receive their highest levels of knowledge from 'other companies' rather than universities, public sector bodies or test centres.

Assessment of established networks proved more complex and less insightful than was initially hoped. Accounting for non-mutually exclusive established networks (i.e. established networks within established networks) clearly needs further refinement. Additionally, since a high ratio of non-system actors (who were clearly not interviewed) made up most networks, almost all of these sub-networks proved un-assessable in anything other than basic 'aesthetic' and 'intuitive' ways (as the networks were incomplete) without making strong assumptions on reciprocity.

9.5.2c Full Network Knowledge Generation and Diffusion

One of the key problems of full-network assessments was that there were no alternative networks to benchmark findings of and therefore (unlike individual and sub-group analysis), only the different knowledge network type comparisons could be used and the 'absolute' level of density/average ties could not be critically commented on, (i.e. whether to say that a full network average cohesion value of 0.0955 was high or not.)

9.5.3 Market Formation

High levels of overall heterophily were seen using between actor types and between nationalities which showed a general prevalence for interaction with non-similar stakeholder types.

9.5.3a Inclusiveness and Average Ties

Both inclusiveness and average tie strength provide some valid information however, the implications of inclusiveness from a policy setting perspective are perhaps less apparent than it is within the average tie-strength. Here it is interesting to note that the perceived average tie strength of technical interactions is lower than the other knowledge fields and that those non-system actors (on average) provide stronger technical interaction). This does suggest, (when accounting for the higher level of technical inclusivity of system actors and summated density which is similar to that of the technical density) that there are a high number of lower-level technical interactions occurring between system actors (rather than a simply a small number of highly contributory non-system actors).

9.5.3b Density

Absolute values as well as average density was clearly important when assessing sub-groups and nationalities for, (as was mentioned in Section 9.5.2b above) low levels of respondents, (from either a sub-group type or nationality) could be identified and discounted when looking at the summated interaction values, especially given the wide variety of absolute levels (4-2500+).

Sub-group intra-activity (i.e. between stakeholder types or countries) between those that could not be discounted, (i.e. England and Scotland nationally and device developers, public sector bodies, universities and test centres by sub group) showed significant variations in different actor types, (e.g. Scotland has high relative density while device developers did not.)

9.5.3c N-Clique

N-clique analysis, as with the above density metrics, required some data manipulation before the analysis could be conducted. Again, this meant that options for both interpretation (and repeatability) had to be considered when choosing the many permutations available. The output result however showed cliquish behaviour of a lower order within England specifically and among universities (at lower levels of dichotomy) and, as would be expected given the nature of their function, less so at high levels between utilities and between device developers.

9.5.3d Homophily

The homophily measure showed on average that there was high levels of heterophily between actor types in all except the national market/fiscal knowledge networks in which there was a very slight inclination towards homophily. Highest levels of heterophily were between environmental stakeholder types, (i.e. environmental universities and device developer types).

9.5.4 Development of Positive Externalities

The application of SNA for the identification of interactions and learning from non-system actors as an indication of positive externalities proved beneficial not only due to the very clear, quantifiable and codifiable resulting data, but also because prior indicators of positive externality are themselves very much more tacit and narrative in nature, (see section 9.3.8 within this chapter).

Having a stronger indicative metric of knowledge spillovers and natural search heuristics can be used to help identify where aligning sectors and cross supporting policies could be implemented. Although there is clearly less qualitative insight from the network metrics, the application of SNA to identify out-of-sector contributions provided a clearer parametric comparator for contributions from different countries, different industries and different knowledge fields. For example, identifying that strong technical externalities of influence are provided to English actors compared to Scottish actors (non-system actor contributions of 435 and 138 respectively) shows that the Scottish system has a far higher level of internalisation (in terms of the system rather than the country) than English actors do. Breaking down these more aggregated details, Figures 43 through 45 within section 7.5.1 of the Additional SNA Findings Chapter show much richer insights as to the external contributing actors to the sector. Identifying specific 'outliers' such as major environmental contributor Xodus Aurora and Aquatera (within the environmental field) or HMRC (in the technical field) provides valuable details of who and where knowledge influence is coming from.

Further to this, strong indicative findings could direct researchers as to system boundary constraints for future iterations of the study, (for example, a high level of non-system market/fiscal knowledge is obtained from what is currently non-system public sector bodies which could be *internalised* within future assessments).

9.5.5 Entrepreneurial Experimentation

Structural brokerage was not straightforward as a metric and the appropriability of the metric itself was questionable given that the theoretical assumptions behind the metrics of constraint and effective size themselves. This includes the underlying premise that actors are 'substitutable' which is true for some relationships, (i.e. when assessing supplier brokerage or some contracted research) but is clearly not for others, (testing of devices at EMEC, interacting with statutory environmental consultees). Some rough heuristic findings, such as the network constraints of device developers seem understandable as does the effective technical network size of universities (who have many options for collaboration). Additionally, filtering the constraint and effective size tables to only include those actors who are active within the network was clearly also necessary. When looking at peripheral actors within the different epistemic networks however (such as the Scottish Government being rated as highly constrained within the environmental network), it does not seem valid to suggest that those most constrained are positioned so *to their own detriment* as a stakeholder since they are themselves simply not active within that field.

9.6 Conclusive Remarks

In conclusion to the Methodological Discussion section, it has been shown that there have been a number of insightful methodological insights regarding appropriability, applicability and 'operationability' of the more status-quo metrics given within the standard analysis.

The first of the initial research questions can now be addressed within some clarity since the applicability and validity of the various innovation metric tools have been explored in greater depth.

Returning to the second of the primary research questions within the thesis, (how insightful are the various methodologies for system functionality analysis and how replicable are they), it can be seen that although many provide insight in a broader level and signpost researchers to narrative points of interest (such as identification of knowledge types or taxonomies of established networks), others clearly have limited applicability within this particular case study of analysis. Identification of which prove useful over which is unfortunately something that must be done on a metric-by-metric basis and the applicability of these is also kaleidoscopically affected by the technical complexity, maturity and size of the system under analysis.

As with existing metrics, the applicability of social network analysis as an extended tool for understanding TIS varies by the system under analysis however has been shown to provide a strongly correlated indication of innovative activity (against proxies such as TRLs, patents etc.). It has also provided a structural understanding of the system that is original and insightful in its own right. Again (and as with established metrics); from the application of SNA, outliers and broad trends within the data and their related functionalities have been identified at varying levels to provide for narratives of understanding which could not be obtained through conventional TIS measures and is ultimately more insightful than proxy measures alone could provide.

From a policy perspective therefore, there are clearly some limitations to how and when network analysis could work as a tool for understanding the knowledge diffusion of networks, (i.e. when the system is too large, too fragmented or issues of appropriateness/secrecy are prohibitive for practical analysis). There is however also a strong argument for its application within certain systems of analysis such as emerging niche markets or strongly integrated 'problem solving' industries (what could be described as Science based or specialised production intensive industries using Pavitt's taxonomy)(Pavitt, 1999). There is also a great deal of promise for its original application within novel systems such as informal innovative networks as found within developing communities. Suggestions for future work such as these are discussed further within section 10.4 of the following chapter, the System Discussion. As well as providing a conclusive statement on future work, this final chapter explores the system findings of the analysis undertaken within a narrative format and the relevance of these findings to policy within the wave energy sector, (rather than looking at applicability of methodology).

10. System Discussion Section

Table of Figures:

Table of Tables:

10.1 Chapter Introduction

The many metrics and proxy indicators from the earlier Established Findings and Additional Findings chapters are synthesised within this chapter to present an overall analysis of the sector from a system analyst, (policy advisor) perspective. Here Bergek's indicators are used to conduct the latter stages of analysis within the TIS model (Bergek *et al.*, 2008a). Although Bergek and others have often simplified analysis to a diagrammatical representation of functional activities interaction, this analysis will take a more narrative approach as this format can address the findings of the study more comprehensively than a single diagram could. The findings are divided as follows:

- A discussion in terms of positive policy findings (i.e. what is actually occurring within the sector) based on the evidence found within the primary systemic and synthesised systemic findings.
- A final section provides normative policy suggestions (i.e. in terms of what could be done to assist), based on the application of the evidence and current theories of innovation, policy and economics discussed within the literature review to produce the Policy Recommendations section.

10.2 Assessing the functionality of the TIS & Identifying blocking mechanisms

10.2.1 Comparative Assessments

As described in the research question chapter, an intrinsically difficult element of innovation systems approaches comes when attempting to benchmark the success of a process or functionality. One methodology for achieving this identified by Bergek as 'system comparisons' (Bergek *et al.*, 2008a) is to conduct a comparative benchmarking exercise of different nations, sub-groups or (in this case) knowledge fields within the system of analysis. Below is this comparative discussion broken down into different established networks, patents, countries, (specifically England and Scotland), individual actor, sub-groups (i.e. stakeholder types) and device developers. As mentioned above, the findings are based upon a synthesis of all 51 raw metrics (combined into 33 proxy indicators) from the different (established and additional) TIS methodologies as well as qualitative discussions with all 43 interviewees.

10.2.1a Different Established Networks

As discussed within the Established Findings chapter, there were found to be four types of network active within the sector: Industrial representation networks, public research project networks, academic collaboration networks and regional economic networks; their dominant characteristics are listed below:

Network Type	Number Identified	Member Size	Network Leaders	Geographical Distribution	Network Focus
Industry Rep.	3	Large	Industry	National	Industrial representation, lobbying and communications
Public Research Project	5	Medium	Public Sector	Inter-/ National	Sector-wide technical research on bottlenecks. Finite time and funding
Academic Network	4	Small	Academia	Regional	Joint research and problem solving as well as collective lobbying/tendering ability
Regional Economic Network	5	Any	Public Sector	Regional	Regional economic development interests

Table 79: Established Network Types Summary

These four identifiable subgroupings present the potential (allowing for non-competing aspects such as research tendering etc.) for collaborative learning given their common mandates, shared concerns and overall membership profiles. There may also be justification for coordination and collaboration between these networks in terms of research activity to ensure that overarching concerns (such as funding for the sector, skills, research requirements and lobbying messages) are clearly identified, coherently conveyed and non-overlapping.

One final point of note is that there are clearly a high number of Scottish-only networks (6 specific networks that have some marine energy element to them) and as a result, the top four network-participating stakeholders are all based in Scotland, (University of Edinburgh (7 networks), University of Strathclyde (5 networks), EMEC (5 networks), and Heriot-Watt University (4 networks)).

10.2.1b Different Patents

It is hard to suggest what the singularly most influential patent is since the aspects of patent centrality are more complex than system actors. Secondary levels of influence (i.e. how influential patents that were influenced by an initial patent were) and beyond (3rd and 4th degree 'network horizons') are clearly more relevant than may be the case with actor networks. Likewise, timescales of reference are also longer than with actor networks (can patents from 50 years ago still be said to have the same level of influence that they had initially?). Although these questions are somewhat beyond the scope of this study, the four most influential patents within the UK (as taken from the EPO and regardless of date) for measures of direct and secondary degree as well as harmonic closeness and betweeness centrality are listed in Table 80 below:

In Deg.	In 2 Loc.	Harm. Clos.	Betw.	Title	Publication date	Inventor(s)	Applicant(s)
1	-	-	-	Wave energy converters.	09/09/1981	FARLEY FRANCIS JAMES MACDONALD	SECR DEFENCE BRIT [GB]
1	-	-	-	Water action powered pump	08/06/1976	HOOPER III LEE EZEKIEL	HOOPER III LEE EZEKIEL
1	3	3	-	Wave power generating apparatus of air-circulating type	15/01/1986	WATANABE KUNIYA	TOHOKU ELECTRIC POWER CO
-	1	2	-	Tidal power plant and method of power generation	04/07/1978	WOODMAN HARVEY R	WOODMAN HARVEY R
-	-	-	1	Energy conversion apparatus	06/02/1985	PEATFIELD ANTHONY MICHAEL ET AL.	PEATFIELD ANTHONY MICHAEL

Table 80: Most Influential Patents within the GB Wave Energy Sector

The first of the three joint most influential in-degree patents (with a network horizon of just 1), "Wave energy converters" (EP0035346a2) patented in the early 80s by the then Secretary of State for Defence was cited by five other UK wave energy patent, (one of which, by the same inventor was GB2433553, a patent itself cited by the most technically mature device developer; Pelamis Wave Power (WO2011/061546 A2) in the latest revision of its main device design (Farley, 1981, Farley, 2005, Yemm and Henderson, 2011). This is illustrated in Figure below.

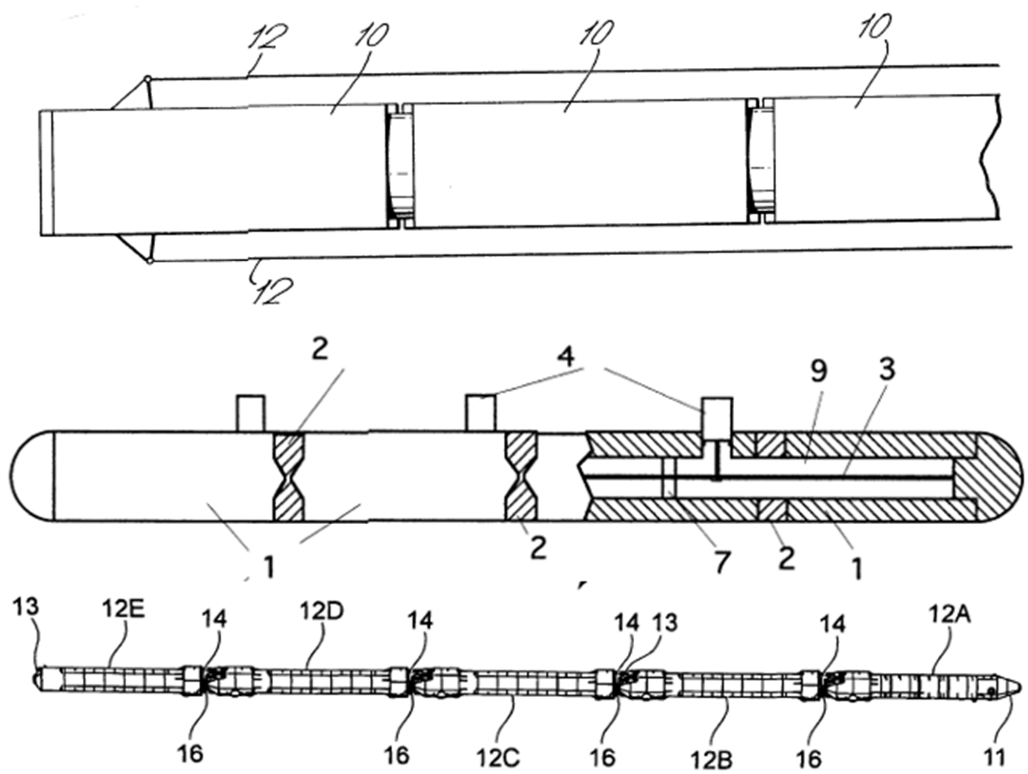


Figure 113: Evolution of Patent Influence: From the Most Cited Patent Overall (Top, Dated 1981) Through to the Latest Pelamis Primary Technology Patent (Bottom, dated 2011) (Farley, 1981, Farley, 2005, Yemm and Henderson, 2011)

When analysing the 2nd network horizon, (i.e. those patents that have had the highest level of influence upon influential patents themselves calculated by simply summing the 'grandchildren patents' of influence), it can be seen that 'Tidal power plant and method of power extraction' (US4098081) has been of highest influence. This is mainly because it in turn influenced one of the highest in-degree scoring centrality rated patents, 'Wave power generating apparatus of air circulating type' (GB2161544) as well as the almost equally influential (and highest betweeness centrality rated patent), 'Energy conversion apparatus' (GB2143284)(See Literature Review section 2.4.2a for descriptions of centrality). This relationship is shown graphically within Figure 114 below.

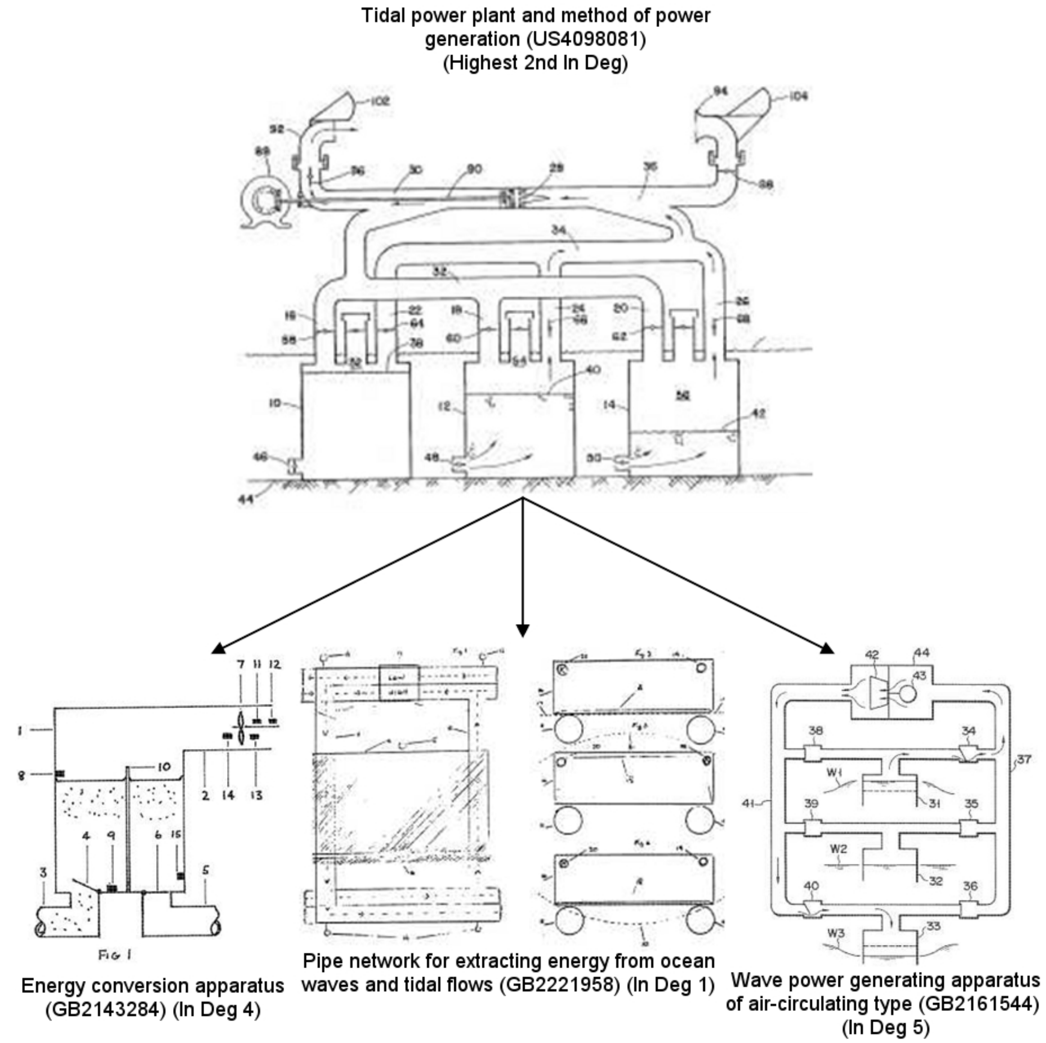


Figure 114: Secondary Patent Influence of 'Tidal power plant and method of power generation'

It should be noted that the level of centrality that these patents holds does not relate to the commercial value (either fully exploited or otherwise) of these patents but rather, the overall innovative influence that they have had to UK patents.

10.2.1c Different Countries

From both the network analysis as well as discussions with stakeholders, Scotland is clearly perceived as both the most active country within the sector as well as the most promising in terms of future development, as shown in Figure 115 below.

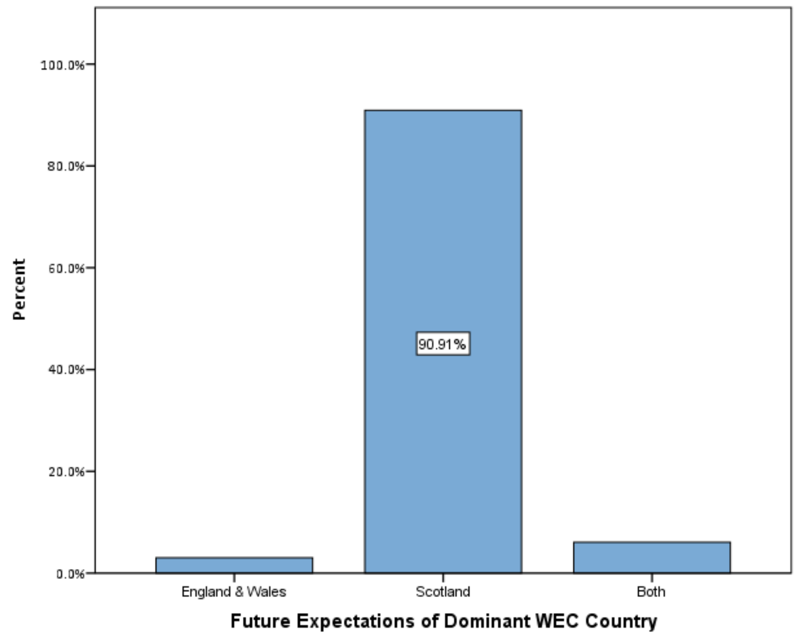


Figure 115: Respondent Expectations as to which Country will be most dominant in the sector by 2050

This is also supported by the device developers' expectations of deployment for 2020, where Scotland has a far higher deployment expectation, as shown in Figure 116 below.

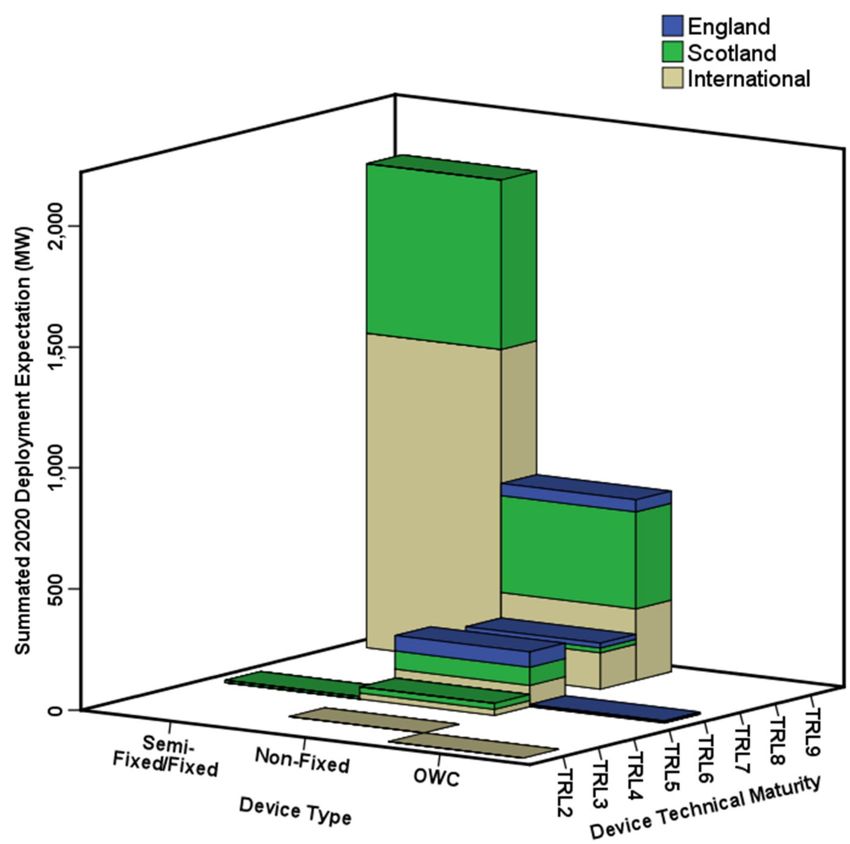


Figure 116: Device Developer Deployment Expectation for 2020

Clique analysis however (detailed in the Market Formation section of the Additional Findings chapter (S7.4.4)), shows that although the University of Edinburgh is far more prominent and influential than all other universities within the sector, England currently has a more cohesive internal technical knowledge research network. The additional findings chapter suggests a few reasons for this: Firstly, that the University of Edinburgh's research interactions are both international in nature and between a wider array of stakeholders (whereas many of England's universities work very heavily with other English universities). Secondly, besides Edinburgh, although there are several high performing universities within the sector (which normalise the score) they on average collaborate far less within the technical field of the wave energy sector than English universities. Scotland also provides higher levels of technical influence to non-Scottish actors (i.e. the rest of the UK) than England does, however (unsurprisingly given the capital location of most public sector bodies), England has a higher level of market/finance and environmental/planning influence upon all other UK nations (including England itself) than Scotland does. Overall though, from a network perspective Scotland has a higher level of summated internal cohesion. It should be pointed out that international actors were the most referenced overall in sheer numbers (i.e. referenced by all system actors) however the sum weighting of these references fell far shorter than the sum totals between nations showing that although there are a high number of international interactions occurring, they are of far lower average intensity than those within the UK.

From an industry perspective, despite the recent matching of ROC support for wave energy between the two countries (5 ROCS) (DECC, 2012a), Scotland has a clear first mover advantage over England and a far stronger political appetite for deployment (as discussed in the Government Representation of Legitimacy section of the Established Findings chapter (Section 6.2.2a and b)). This is partly as a result of legacy advantages (i.e. Edinburgh's research pedigree, the most advanced device developers, EMEC and large utilities companies with prior experience of renewable energy being located within Scotland). Partly it is as a result of its larger natural resource and partly as a result of its strong supporting skills base in offshore oil and gas. With declining reserves in these fossil fuels, marine renewable energy could be seen as a potential economic and employment opportunity for the current skilled workforce and complimenting industry. This has been assisted further with the recent release (after the bulk of the research detailed here was conducted) of £103m of funds collected under the fossil fuel levy from the UK treasury to the Scottish Government for the commercial assistance of the wave and tidal energy sector (BBC, 2011, Mitchell and Connor, 2004). Additionally, the announcement by the Carbon Trust that the Scottish Government paid £15m Marine Renewables Commercialisation Fund (MRCF)(Carbon Trust, 2012).

At the time the primary research was conducted, there was very little research work being conducted within Wales and although there were some prominent actors within Northern Ireland (specifically Queen's University Belfast which has worked heavily with Aquamarine Power and the developer company Pure Marine Generation Ltd), the scale of this activity was relatively small in comparison to both Scotland and England. Although research activity in Wales has increased slightly over the past year it is likewise far from England or Scotland's level of activity.

10.2.2d Individual and Group 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. ΣW-In	Stakeholder Type
1st	Crown Estate	82	Other Company
2nd	Marine Scotland	78	Public Sector Body
3rd	EMEC	70	Test Centre
4th	Scottish Natural Heritage	53	Public Sector Body
5th	DECC	49	Public Sector Body
6th	Aquatera	40	Other Company
7th	Xodus	39	Other Company
8th	Marine Management Organisation	35	Public Sector Body
9th	Aquamarine Power	31	Device Developer
10th	DEFRA	28	Public Sector Body
11th	Heriot-Watt University ICIT	27	University

Rank	Company	Market ΣW-In	Stakeholder Type
1st	DECC	82	Public Sector Body
2nd	Carbon Trust	69	Public Sector Body
3rd	Scottish Enterprise	63	Public Sector Body
4th	Scottish Government	56	Public Sector Body
5th	Aquamarine Power	49	Device Developer
6th	Scottish Renewables	48	Industry Association
7th	RenewableUK	44	Industry Association
8th	Highlands and Islands Enterprise	42	Public Sector Body
9th	Technology Strategy Board	39	Public Sector Body
10th	Scottish Power	34	Utility Company

Rank	Company	Tech. ΣW-In	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 81: 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 82 below:

	Summated	Environmental	Technical	Market
Primary Actors	Mixed (With Small World Properties)	Public Sector (Regulators)	Universities	Public Sector (Funding Bodies)
Secondary Actors		Environmental Consultancies	Device Developers	Mixed

Table 82: 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 83 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	8.00	5.00	46.00	56.33	19.67	38.00
	Utility Company	10.40	4.60	17.40	26.80	11.80	8.80
	University	4.71	4.43	55.93	13.07	12.14	21.57
	Public Sector Body	6.40	13.60	5.20	43.80	21.20	9.20
	Device Developer	6.64	3.57	19.21	25.43	0.43	22.36

Table 83: Average system actors levels of knowledge reception for the UK wave energy sector

As can be seen from Table 83, 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 81) 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 83 quantifies broader claims outlined earlier within the introduction chapter of this thesis 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. between 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*). Table 84 below shows the distribution upon the TRL scale for all 14 device developers interviewed.

	Research Stage Description	TRL	# of UK Developers
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 84: 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 85 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 85: Correlation of Different In Centrality Values to Technology Readiness Levels for Device Developers

From a perspective of legitimisation of technologies, there is additionally a visible relation between the number of established networks, (such as trade associations and stakeholder groups) that device developers are active members of and their overall levels of technology maturity. Although device developer representation does exert strong influence within the sector (and to great effect), specifically from the Forum for Renewable Energy Development in Scotland’s Marine Energy Group (FREDS-MEG), the Pentland Firth & Orkney Waters Developer’s Forum and through RenewableUK, these established networks are very much dominated by leading edge technology developers. No device developers below TRL5 are active within any established networks as identified within the Formation of Networks section of the Established Findings chapter (Section 6.7.1). This relationship between TRL and network interactivity is shown in Figure 117 below.

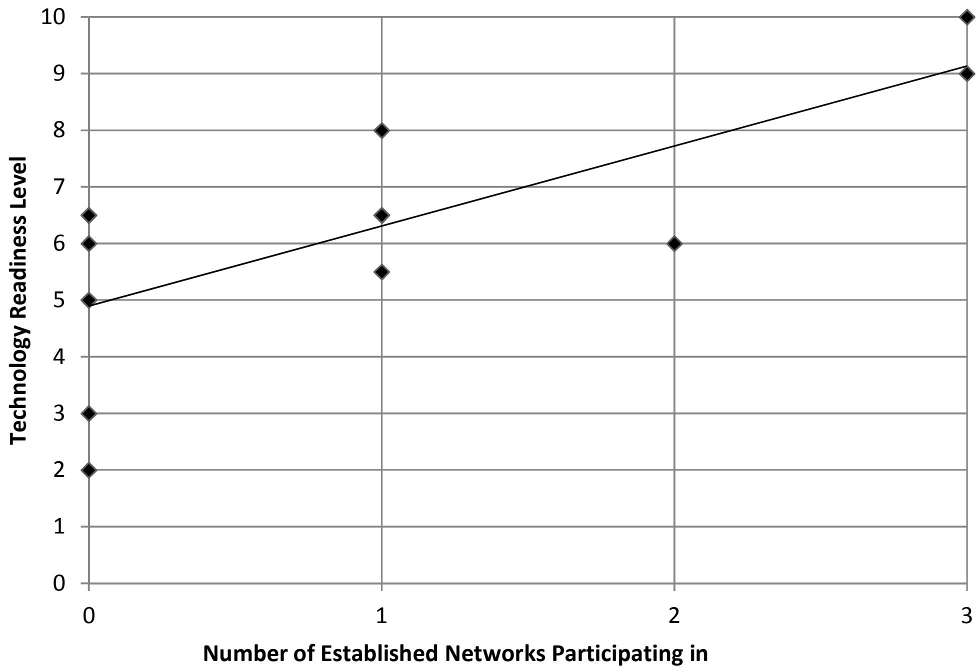


Figure 117: Device Developer Established Network Engagement Against Technology Maturity

10.2.2 Policy Findings

10.2.2a Government Technology Gating

The influential state of positioning for the most mature device developers identified in section 10.2.2d above, 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, 2005a). 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, 2005a)

The failure of the MRDF to inject funding into the industry was 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, 2005b).

To overcome this failure of the MRDF, 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 fund (consisting of £22.5m), 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 a purely capital support fund providing 60% of a developers' first, full-scale commercial projects (to a maximum of £6m per project) (Carbon Trust, 2009b). 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.

Over the same period that the MRDF and MRPF were available, the devolved administration of the Scottish Government also financed wave energy initiatives within Scottish waters specifically with two main programmes. The first was the £13M Wave and Tidal Energy Support Scheme (WATES) announced in 2006; like the MRDF, this provided £100/MWh of energy generated but also supported capital grants of up to 40% of costs as well as having less stringent access conditionality, was accessed in conjunction with MRPF funding (Renewables Advisory Board, 2008, Scottish Government, 2009c). The second scheme more recently announced in 2010, the Wave and Tidal Energy: Research, Development and Demonstration

Support Scheme (or WATERS) provided a further £13 to a set of developers in the form of a 100% grant (Scottish Government, 2010a). Both calls were for wave and tidal devices however the primary wave energy beneficiaries of these programmes were the two leading technologies (indirectly receiving over £3m each for deployment over both calls)(Scottish Government, 2010c).

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, 2011c). The Carbon Trust also announced the (Scottish Government funded) £15m Marine Renewables Commercialisation Fund (MRCF) for the same purpose of array support to run from 2013 (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, 2012a). 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 84 as the current UK market leaders (DECC, 2012b, 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 unqualified '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, 2011c, 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 84 above) a government funding gate of projects has been created as can be seen graphically in Figure 118 below.

YR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
TRL 8-9 (Commercial Arrays)											
GB									MEAD		
Scot									MRCF		
TRL 7-8 (Commercial Projects)											
GB		MRDF									
GB	CCL Exemption Cert.										
Scot								The Saltire Prize			
Scot	1 ROC/MWh		RO Scot. MSO		RO Scot. 5 ROC/MWh						
Eng	1 ROC/MWh				2 ROC/MWh				5 ROC/MWh		
TRL 6-7 (First Grid Connected Unit)											
GB					MRPF						
Scot		WATES				WATERS					
TRL 5-6 (Sub-System/System Part Validation in Environment)											
GB			TSB Funding								
GB					ETI Tech. Prog. (<5 + Non Device)						
GB		MEA (<5)									
TRL 4-5 (Component/Sub-System Validation in Environment)											
GB	EU FP(6-8) Funding (<4 + Non Device)										
GB	Research Council Funding (<4 + Non Device)										
TRL 3<4 (Component/Sub-System Validation in Lab)											
TRL 2<3 (Proof of Concept, Experimental Function)											
TRL 1<2 (Concept or Application Formulated)											

Figure 118: Graphic of funding landscape available for UK wave energy developers with *gating* at TRL6-7

This gating has resulted in the economic equivalence 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)) as can be seen from Figure 117 above.

The second dimension, (and one strongly voiced by a large majority of device developers below the TRL6 threshold) 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 direction of the technical search heuristic (*internal influence upon the direction of search*) - the mechanisms by which supporting and regulatory policies are formed - and argue that they are unable to gain sufficient ‘access’ to decision making policy formulators. 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 as can be seen in Figure 119 below.

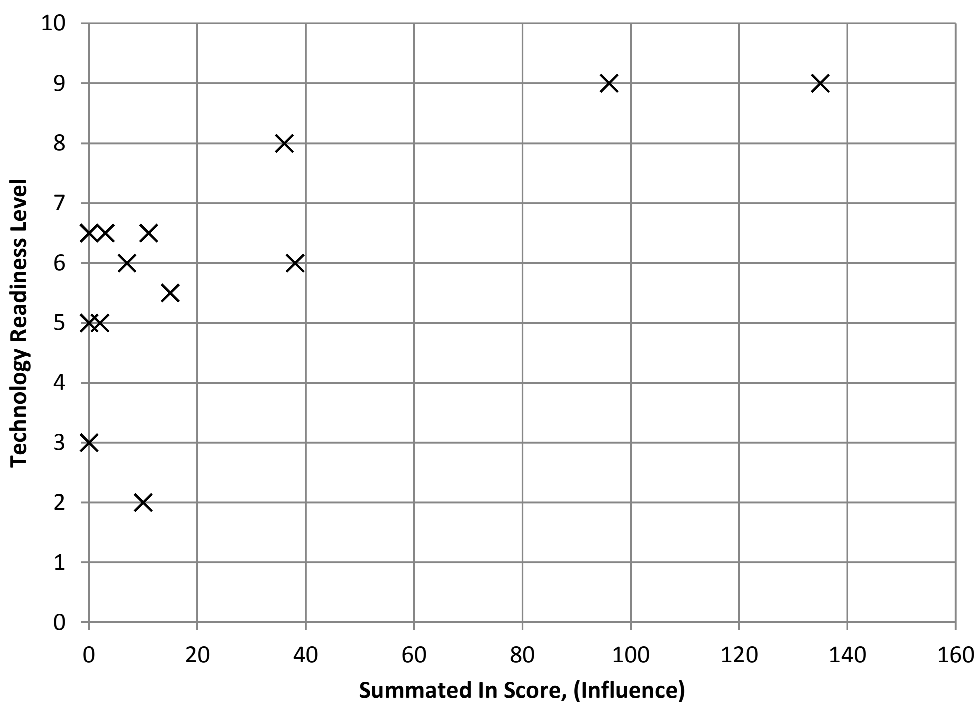


Figure 119: Influence of device developers within the system against technical maturity of device

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, 2010c). Although it could be seen therefore as the role of the Carbon Trust or ETI to support first full scale devices to deployment, this does not address where the funding for such programmes, (given the £10m+ requirement per device) should come from.

Technological convergence (and the increased experience and technology confidence gains that this bestows), could be argued as a necessity. It can be expected 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 the several negative impacts:

Firstly, the lack of transparency in the financial decision making process reduces the overall perceived legitimacy of the system for early stage developers who perceive a lack of 'equality' among developers to be unfairly bias against them. This could lead to a higher number of market exits and thus a relative reduction in *entrepreneurial experimentation*.

Secondly, there is a higher likelihood of technology lock-in. The disadvantages of technology lock-in are borne out of the fact that it is not always the technology with the highest development potential that is selected (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.* highlights 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 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, following on from the second point, the creation of higher market entrance barriers as technology requirements become increasingly more stringent 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) where technology can effectively be bought by overseas companies and either re-located overseas or simply incorporated into their own business (which would itself result in a lower level of domestic spend 'sink'). This could occur as a result of the less disaggregated supply chains for second or third tier products and internal competition.

10.2.2b Policy Support Structure

Although there is a lack of appropriate funding continuity for wave energy developers beyond a certain point, this gating may 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.

10.2.2c Disjointed Nature of Support

Chapter 3 identifies that there has been a historical lack of funding continuity and that favourable support has been intermittent since the mid-1970s (Carbon Trust, 2006). This has been the result of factors including fossil fuel price fluctuations, changes in central government agendas and industry failure to deliver upon expectations. One effect of funding intermittency has been a high level of device developer turnover; including the McCabe Wave Pump, Orecon, the Osprey, the PS Frog, Bristol Cylinder, Wave Master, FWPV (Floating Wave Power Vessel), Sea Clam and the Lily Pad. Many of these devices did not make it to full scale prototype and failed due to a lack of funding continuity rather than lack of technical merit. This pendulum of support however has swung both ways with one university suggesting that there was a 'spending rush' in the 70's/80's to spend research funding while it was available from central government: "I remember getting out bits of equipment that must have cost tens of thousands of pounds at the time and they'd never come out of their box. It became a case of: 'We've been given £500k and we've got to spend it'."

These days, there is a large and diverse range of funding bodies supporting the UK wave energy sector including: the UK research councils, the Technology Strategy Board, the Energy Technology Institute, the Carbon Trust, the Department of Energy and Climate Change, the Scottish and Welsh Government (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 or the Crown Estate. Almost all of these bodies hold different funding motivations which including carbon abatement, technology progression, regional economic growth and infrastructural improvement (as outlined further within the Methodological Discussion, Resource Mobilisation Section (9.3.1a). 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 (in terms of providing funding continuity for research/technology progression) or provide efficacy in supporting the goal of commercialising the sector. This mosaic of funding and motivations has been identified by various studies as detrimental towards the growth of the sector and was highlighted by interviewees as being problematic for their work. Indeed, the UK National Audit Office recently stated that “Coordination of direct support for renewable energy has historically been limited, with each delivery body developing its own approach in accordance with its own objectives” (National Audit Office, 2010). Recent examples of the lack of cohesion between policy timescales (often aimed at different device TRLs) include:

- The failure of the MRDF and its deployment timeline (discussed both within the Background Review of the Sector chapter and within the Government Gating section above).
- Environmental baseline surveys and monitoring work for marine deployments which was highlighted by one environmental public sector body. This is often required to begin 2 years before deployment of a device and has presented large challenges when conditionality of public funding often required either full deployment or site licence approval by a certain (prohibitive) date or timeframe.
- The Kreab & Gavin Anderson investment report (commissioned by DECC) highlighted that venture capitalists perceived timescales of the investment opportunities for marine energy was longer than their (roughly 10 year) investment profiles, reinforcing the comment made by developers (above) regarding lack of chronological continuity in support (Kreab Gavin Anderson, 2010).
- Changes in the primary revenue support systems, such as the future introduction of a CfD FiT (which the UK Government is now consulting on), along with continued changes in the various financial mechanisms has resulted in high investor uncertainty. As one prominent device developer CEO

mentioned in his blog: "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)

10.2.2d Technology Support 'Bundling'

Wave energy technology is perceptually and historically often aligned with tidal technology in policy decisions under the umbrella of 'marine renewable energy' due to the historically similar stages of technical maturity. Over the last few years however it has become clear that tidal technology has advanced faster than wave energy this increased legitimacy a result of the following factors:

- Cost and technology uncertainties for shallow tidal stream devices are generally more established and less uncertain than wave energy. Levelised generation costs expected to be between 20-30% cheaper per MWh across all comparative stages of technology maturity, (DECC, 2010b, Committee on Climate Change, 2011, Energy Technologies Institute, 2010, The Offshore Valuation Group, 2010, Allan *et al.*, 2011, Carbon Trust, 2011c)
- Despite there still being a degree of diversity of technological options, there are clear signs of technology convergence within the tidal energy sector towards three bladed horizontal axis turbines. These now make up 18 of the overall 31 UK based tidal technology developers (EMEC, 2012, LCICG, 2012).
- The generation profile for tidal technologies fits better into the current electrical generation regime due to it's almost 100% predictability. This means that under the RO system, longer term contracts and a higher £/MWh rate can be received than with wave energy whereby reliable generation forecasts are not available until days beforehand. It should be noted that the introduction of a "contract for difference" feed-in-tariff system (as currently being suggested by the UK government) would not eliminate this advantage since intermittency of wave energy generation would still create a higher risk profile for contracted counterparties (those selling the electricity on the open market) who would therefore expected to pay a lower average 'strike price' (the agreed price of generation) per MWh (DECC, 2011d).
- Despite the difference in expected generation cost, the support for both wave and tidal technology within England is set to become identical at 5ROC/MWh (DECC, 2012a).

- The UK practical resource has recently been re-evaluated by Salter among others and is now estimated to be between 18-200TWh/yr within the UK (as opposed to the wave energy resource that is estimated to be around 40TWh/yr) (Salter, 2009, Committee on Climate Change, 2011, The Offshore Valuation Group, 2010). Although the global practical resource for wave energy is still expected to be far higher, this difference offers suffient potential to impact on issues of security and reliability of supply within the UK as well as providing important potential for a strong home market for tidal technology manufacturing.

Although there is still the potential for more innovation *shocks* within this sector, the risk of this occurring is declining as many more tidal developers have now managed to deploy at full grid connected scale (EMEC, 2012, Vantoch-Wood *et al.*, 2012, RenewableUK, 2012).

The above points have lead to what Negro *et al.* describe as 'Attention Shift' of policy support from wave energy technology towards tidal generation (Negro and Hekkert, 2010). As a result of this, the current milieu of support instruments focusing on post-prototype deployment and array deployment through higher revenue to grant gearing is more appropriate for the tidal industry.

Supporting wave and tidal technologies together is intuitive and beneficial within certain fields (e.g. examining planning and grid issues or aiding in cost reduction for communalised intermediate goods such as sub-sea connectors) as discussed further within the Development of Positive Externalities section of the Established Findings chapter (6.8.1a). Nonetheless, it does not provide for specific enough innovation instruments for the increased breadth of technical maturities that are still present among device developers within the wave energy sector.

Additionally, there is also a large movement within the offshore wind energy sector as UK 'Round 3' sites begin the process of planning, while 'Round 2' (as well as 'Extension' sites) move through construction and commissioning. Although wind sector activity has substantially supported the refinement of marine energy planning and laws in general (for example, bringing offshore generation into the focus of recent marine spatial planning legislation within the Marine and Coastal Access Act 2009 (UK Government, 2009b)) it could well divert efforts to commercialise wave energy technologies since UK renewable energy generation targets are themselves non-technology specific.

10.3 Policy Recommendations (Specifying Policy Issues)

Building on from 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.

10.3.1 Clarity of Government Funding Rational & Standardisation

The disaggregation of support landscape for wave energy is not wholly that of regionalisation versus centralisation as an approach, although coordination between regional and centralised funding and support bodies would clearly be beneficial (if perhaps problematic given the issues of compatibility outlined by Smith (Smith, 2007)). This is more clearly relevant for devolved administrative support such as the Scottish or Welsh government and 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. Scotland is clearly a more supportive business environment for wave energy however it is still required to work closely with central government. Since the abolition of the regional development agencies in April 2012, the landscape of regional support bodies (within England at least) has become far more fragmented. The necessity therefore for *technology* focussed support at this nursing stage of sectoral maturity which 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). In this instance however, it is clear that this shared future is itself not even coherent within government. The recent announcement of the Low Carbon Innovation Coordination Group has been formed to help assist with this recognised problem however its efficacy in doing so has not yet been proven.

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 was the case 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 both 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 metrics.

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. These standards are summarised in Table 86 below[1]:

Focus:	Legitimising Step:	Descriptive:	UK Certifying Body
Company	ISO9000 Certification	ISO9000 is a quality management standard used internationally to assist businesses to create a framework for managing their operational processes	British Standards Institution (BSI)
Technology	CE Certification	CE certification shows that the technology meets certain minimum EU health and safety requirements and thus can provides companies with a better opportunity to enter the European market without having to think about re-designing their technology.	Various
	Technical Verification and Certification	DNV have a three step technology certification process that ensures that a continuous, risk managed progression of technology development is followed in which the safety, quality of design and expectations of the technology are both optimised and verified	DNV

[1] It should be noted that not all of mentioned certification processes listed are currently fully defined, some are in the process being written.

	IEC standards 62600	The IEC standards 62600 are currently being drafted by the IEC Technical Committee 114 (TC1114). They are specifically designed to ensure that marine energy devices internationally use standardised terminology, assessments and measures for; power performance and resource as well as overarching design and mooring requirements.	International Electrotechnical Commission (IEC)
Project	Insurance underwriting	Essential project requirement for projects that insures against unexpected costs of operation and maintenance. In best case scenario, insurance can cover generation expectation.	Various
	Project Certification	DNV offer project certification that is in effect project due diligence certification to assure that the overall project deliverable expectations (in terms of generation, risk etc) are externally verified and assessed	Det Norske Veritas (DNV)
Other/ Multiple	EQUIMAR Standards	EQUIMAR is a broad project supported by the EU designed to feed into the development of IEC 62600. It contains a scope of deliverables that includes standardisation of both the technology design and resource assessment methods (as with IEC 62600) however it has also works to bring together previous R&D work (by for example EMEC and IEA-OES) and reviewed the sector	None
	EMEC Standards	The European Marine Energy Centre (EMEC) has developed a broad suite of standards and guidelines for a range of marine related activity including: device performance assessment, resource assessment, marine H&S, tank testing and project development	None
	Developer "Due Diligence" Assessment	For large utilities and other developers, the due diligence assessment focuses on both the technology and the company to ensure that not only is the project (and the technology) economically viable but the company behind it is viable both commercially and competently.	Development Company

Table 86: Legitimising Certification Steps for Wave Energy Developers

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 risky appraisal. This by highlighted 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, 2011b)

The overall findings however support an argument that all technology developers commercially operating within the UK, and receiving public funding support should require their technology to be benchmarked and certified based upon the same standard (e.g. EMEC performance assessment). This would need to be done with an explicit recognition that lower performing devices that are at lower levels of technical maturity are not necessarily subordinate to those of higher performance characteristics who are more mature (or indeed vice-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 cost publications 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.

10.3.2 Targeted Support Funding: First Deployment

Combining both ambitious deployment targets and industrial development goals, (with, for example, the Scottish First Minister Alex Salmond describing the Pentland Firth region of

Scotland as "the 'Saudi Arabia' of marine energy" (BBC, 2008)), the UK government's historic level of investment in marine renewable energy not only seems low but has been dwarfed by other countries technology push subsidy levels. Japan for example has spent approximately $2.5b on its solar PV programme while Germany, $782m on wind energy research and both of these technologies are far more mature (IEA, 2010). This is clearly significantly more than the UK's $195m on ocean energy (see Resource Mobilisation section (6.2) of the Established Findings chapter for more). Although Denmark spent only around $300m on wind energy research (still significantly more than the UK on marine energy) and created €5.7b worth of exports in 2008, there were many other factors that aligned for Denmark to translate this into economic success. It should also be noted that many other countries (the US, Sweden among others) also put substantial R&D funding into wind during the same period without the same success. Some of these factors are transferable to UK marine energy sector (such as having a strong home market as well as technology standardisation) however others are clearly not as a result of aspects such as the scalability and motivations for commercial success (Karnøe, 1990, Johnson and Jacobsson, 2002, Jørgensen, 1995, The Danish Wind Industry Association, 2010).

In relation to the earlier section on Government gating, it is clear that there is also a requirement for the creation of an MRPF-like fund for 'first full scale' deployment should policy makers wish to avoid technology lock-in and the opportunity costs that may arise from this. 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. Additionally, access to the future Green Investment Bank (GIB) financing might assist this further 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, 2011b). 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.

10.3.3 Technology Licensing

For many technology developers who lack the commercial acumen and access to capital, assistance in technology licensing may be a potential business model. It was found from the primary interview stage questions as well as qualitative discussion that opportunities exist for patent pooling and licensing among device developers. Five device developers and six universities cited sale of technology as being one of the primary reasons for patenting and many discussed technology licensing and sales as a potential avenue of commercial development. This can be seen from the results of question 1(g) as shown in Figure 120 below, (What do you perceive as the main value of patenting for your company?)

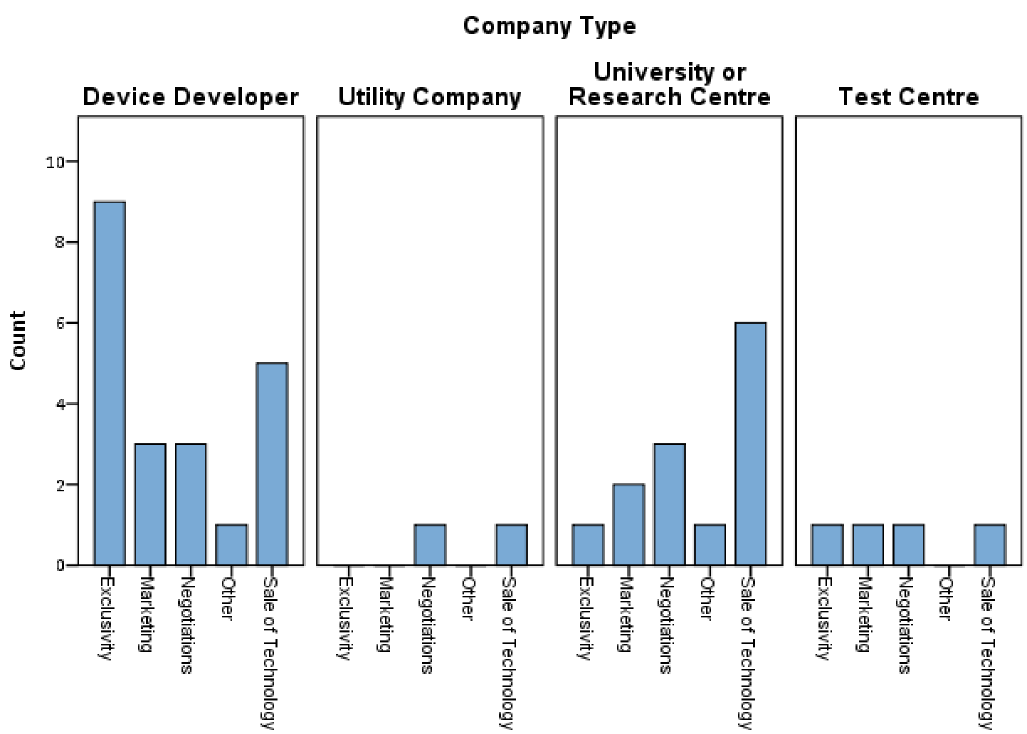


Figure 120: Interviewee's Main Perceived Value of Patenting

Although university interviewees were generally less commercially knowledgeable with regards to patenting and IP options, (such as licensing, pooling or 'spin-out'), most had some form of commercialisation department within the university structure whose role it was to assess, critique and if necessary, assist in the commercialisation of new technologies. Nonetheless, there was a broad scope of qualitative responses regarding knowledge, function and efficacy of these departments within universities ranging from formalised commercial assessment panels to simply non-existents. There was also a mixed response to the perceived value of patents for universities with an overall belief that patents had little value as can be seen from Figure 121 below. This may however be due to the commercial applicability of different research being conducted within different institutes.

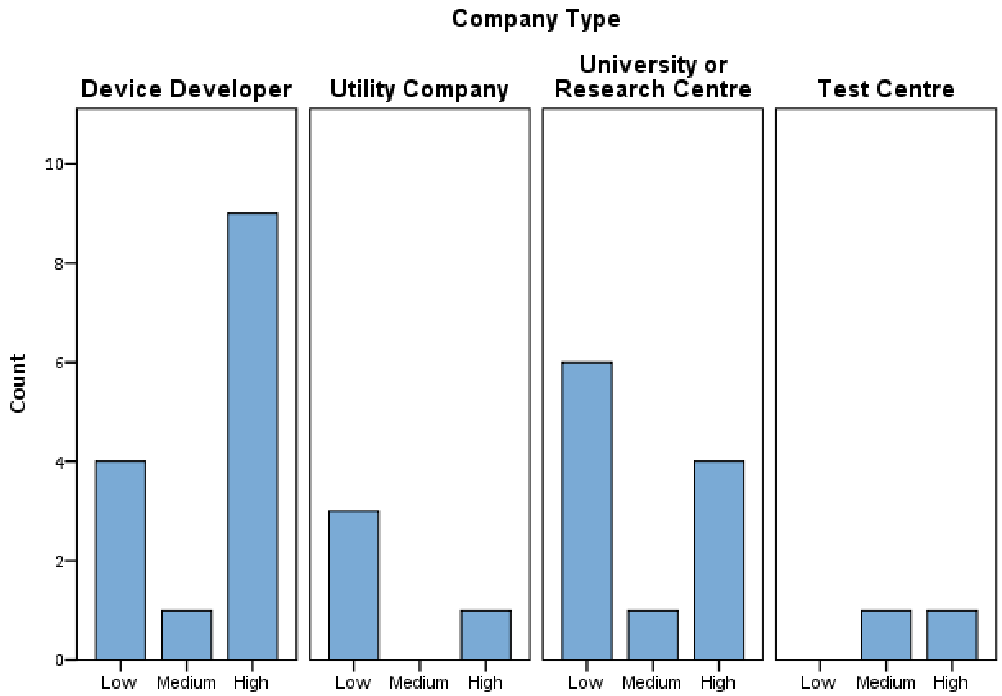


Figure 121: Perceived Value of Patenting

Device developers tended to have a stronger belief in the valuation of their patents (as can be seen from the above figure) however showed higher concern for imitation of their technology.

The opportunity for higher levels of patent licensing and management within the sector clearly exists therefore however there are several obstacles to the achievement of this.

- Search heuristic of 'problem solvers': Although it is not the case for commercial investors, It is currently outside of the search heuristics of most commercial innovators/inventors (i.e. problem *finders* such as universities and device developers) to look outside of their immediate sphere of operation for technical solutions.
- Mixed levels of commercial patent acumen: As mentioned above, universities (and to a lesser extent device developers) had varying levels of commercial acumen when dealing with patents and opportunities for technology spin-out or licensing.
- Commercial neutrality of assisting bodies: One of the primary concerns of device developers was that of confidentiality and, where appropriate (i.e. without prior-agreement and licensing fees) exclusivity of design use.

It could be argued based on the above that a singular point 'patent pool' body would be most effective at overcoming both the bounded rationality of actors and the varied levels of commercial capabilities that are highlighted in the above knowledge sharing problems. As it would need to be a non-aligned organisation (i.e. device developer trustworthy), this would suggest public sector involvement/lead could be most fruitful in gaining the required social capital to manage these portfolios.

A similar mechanism for assisting commercialisation is in fact currently being run in Scotland through Scottish Enterprise's Proof of Concept Programme (PoCP). This programme however has a far narrower focus, working specifically with Scottish universities only (although across a wider range of technologies) but also with a focus on directly supporting pre-prototypes inventions reaching proof of concept stage (Scottish Enterprise, 2012). Within the UK a similar approach could perhaps be managed by UK Trade and Investment (UKTI). It circumnavigates state-aid laws by focussing on universities directly and thus can provide 100% finance (following an assessment process). However this would clearly not be an option within the wave energy sector as so much of the entrepreneurial activity is done within SME firms.

Some companies are already attempting to license patents as their business model for commercial diffusion. One example of this is Trident Energy, whose point absorber device suffered a deployment failure in September 2009 leading them to change their business model and attempt to licence the internally patented linear generator as their primary route to commercialisation (Trident Energy Ltd, 2010). Other companies who are seeking to licence their technology as a route to commercialisation include Trafalgar Marine Technology Limited, who believe their novel 'ferrocement' technology could hold the potential to make dramatic reductions in cost and increased survivability for marine energy devices (Trafalgar Marine Technology Limited, 2010).

Once a patent pool was established, this could be opened up not only to device developers and commercially innovative universities within the knowledge generation sector, but also to non-sector specific actors who have ideas that may contribute to the overall cumulative nature of innovation within the sector. Options such as 'spin-out' patent licensing (from the fore-mentioned developers and universities) as well as what Chesbrough *et al* describe as 'spin-in' innovation licensing from larger manufacturers (such as ABB) could be a potential way to optimally exploit the knowledge being generated within the sector also (Chesbrough *et al.*, 2006).

This patent pool would effectively act as a catalogue of marine energy innovations, sub-categorised into the different sub components within a marine energy device, such as that outlined by Black and Veatch's Carbon Trust Commissioned report: Key Marine Energy

Component Technologies for cost Reduction R&D shown in Table 87 below (Black & Veatch, 2007):

<table>
<tr><th colspan="2">WAVE ENERGY COMPONENTS</th><th colspan="2">TIDAL STREAM COMPONENTS</th></tr>
<tr><td>Cost Centre</td><td>Component Technology</td><td>Cost Centre</td><td>Component Technology</td></tr>
<tr><td rowspan="3">Structural</td><td>Ballast Mass</td><td rowspan="2">Structural</td><td>Piles</td></tr>
<tr><td>Device Body, e.g., float</td><td>Structural Materials</td></tr>
<tr><td>Off-shore Platform</td><td rowspan="2">Electrical</td><td>Generator & Associated Equipment</td></tr>
<tr><td rowspan="2">Electrical</td><td>AC/DC/AC Converter</td><td>Offshore Substation</td></tr>
<tr><td>Generator</td><td>Mooring</td><td>Mooring Components</td></tr>
<tr><td rowspan="3">Mooring</td><td>Anchor</td><td rowspan="4">Mechanical</td><td>Brakes</td></tr>
<tr><td>Float / Weight</td><td>Gearbox</td></tr>
<tr><td>Tether / Fitting</td><td>Rotor</td></tr>
<tr><td rowspan="4">Mechanical</td><td>Accumulator</td><td>Seals</td></tr>
<tr><td>Hydraulic damper</td><td rowspan="3">Control</td><td>Control System</td></tr>
<tr><td>Seal</td><td>Instrumentation</td></tr>
<tr><td>Turbine</td><td>Assembly</td></tr>
<tr><td rowspan="4">Non-Component</td><td>Assembly</td><td rowspan="3">Non-Component</td><td>Construction insurance</td></tr>
<tr><td>Construction insurance</td><td>Design and Management</td></tr>
<tr><td>Design and Management</td><td>Weather allowance</td></tr>
<tr><td>Weather allowance</td><td></td><td></td></tr>
</table>

Table 87: Potential Patent Pool Categorisation Method for Marine Energy Devices

10.4 Future Work

This research has broadly covered three overall strands: Innovation systems analysis and transition theory, the application of network analysis within innovation systems, and the UK wave energy sector itself. Following on from this, there are several potential extensions of research that could be conducted and expanded upon based upon the findings from this thesis itself. Below is a brief outline of some of these potential future topics of research as well as rationale for their undertaking:

10.4.1 Future Research Related to Innovation Systems and Transition Theory

Although the overall framework of the study was conducted using the TIS approach, research upon the application of SNA within other models of innovation and transition theory, such as Geels' Socio-Technical Innovation Systems (discussed in section 2.3.3b) could be extremely beneficial to both fields providing for deeper insights into the transition theory processes between companies, niches, regimes and landscapes. This is discussed further within the Methodology Discussion chapter section 9.4.1.

Following on from the identified taxonomy of established network actor types discussed within the Established Metrics chapter section 6.7.1, there is clearly scope for further expansion and refinement of the type, structure, make-up and operation of these different networks and their activities. One of the potential outcomes from this work could be the identification of opportunities for cross network-duplication and overlap of effort as well as potential for inter network learning, (such as effective methods for providing regional SME business support or collective lobbying power) that could increase the efficacy of these networks' activity. Additionally, there is a wider scope for analysis of cross-network membership using 2-mode network analysis to identify if there is homogeneity/hetrophily between actors and network types or indeed between actors and other actors.

10.4.2 Future Research Related to Application of Network Analysis

Given the identification that un-weighted responses still provide a good non-parametric insight into the most influential actors, (as discussed within section 9.5.2a) - non-weighted metrics could be used within future innovation analysis to provide slightly less detailed, yet much less labour intense SNA research within this field.

Following on from this, the application of network analysis as an indicator for innovation within other emerging industry/renewable energy technology sectors could prove insightful. This could be done either as a historic case study of existing innovation systems based upon formally recorded interactions, (e.g. examining the formation of the Danish wind industry from historic public records of formal research groups/business interactions if they could be obtained) or based upon current emerging systems. This would then help to both provide insight into the different and its formation but also provide a more generalised evidence base for the applicability of network analysis within innovation systems themselves. This would be especially insightful with technologies that are heavily reliant on networks of trust or diffusion such as micro generation technologies, (e.g. installing solar panels where influence and trust in others who have already installed is important) or medium scale biomass networks where distribution networks, distances and 'critical mass' of the networks is vital for economic success.

From a more theoretical approach, the application of network analysis in the understanding of diffusion curves (i.e. the Bass equation) could provide insight into methods for accelerated diffusion of renewable energy technology based upon the identification and targeting of prime movers who have higher levels of influence upon the system (as discussed by Valente (Valente, 2005)).

10.4.3 Future Research Related to the Wave Energy Sector

Keeping within wave energy research, along with the established network research mentioned in 10.4.1 above, a follow up study of the sector in several years would allow for panel data analysis of the network. One of the opportunities that the stage of sector maturity presents is that, since the outcome of the commercialisation is still very much uncertain (i.e. whether the technology will ever be commercially viable or not), it could be that the 'breaking up' of the sector could be observed as funding reduces and actors are left with little resource left for wave energy related interactions. Likewise, if the sector matures and fore-running technologies are 'locked-in' to the technology trajectory; a pattern of network adaptation would be likely to occur that would help to validate or otherwise, academic expectations such as those of Low and Abrahamson who suggest that successful entrepreneurs within growth phase sectors have 'an extensive network of high status individuals that can be tapped to quickly mobilize resources within a narrow window of opportunity' (Low and Abrahamson, 1997).

Additionally, adjustment of actors can be made, (i.e. secondary iterations of system boundaries) to build in or weed out most/least inclusively active actors.

Finally, one further suggested direction for research not focussing upon network analysis could be to broaden the search for clear convergence of technologies within the wave energy sector. This could be done based upon the international device developers list (included within section 6.9.2 of the Established findings chapter), used to contact device developers (as entrepreneurs and the locus of innovation) and obtain further information on their respective TRL's, device classification and patenting histories to see if there is a global convergence towards a dominant design.

10.5 Conclusive Remarks

This final chapter of the thesis has discussed both the findings and normative policy options bought about through the overall research. It has sought to address the third and last of the research questions, specifically what TIS can and has told us about the emerging wave energy sector. Within these findings, we have discovered that there is a polarisation occurring between device developers who are being supported through a non-cohesive 'first-past-the-post' mechanism. Specifically, this has led to a 'Mathew Effect' among these developers which has left many entrepreneurs disillusioned with the process by which government supports the sector. Opportunities for mitigation against some of the negative findings in relation to this work have been presented that include the establishment of a more transparent, accountable and cohesive collaboration between funding bodies. Although this is in the process of establishment through the Low Carbon Innovation Coordination Group, the current lack of detailing on its operation does not provide confidence on its outcome. Other steps for legitimation of the sector such as technology standardisation and licensing which could help to attract investors need the proactive 'buying-in' of stakeholders, (and especially device developers) or more draconian funding conditionality requirements (i.e. benchmark assessing or publishing of performance characteristics), each of which have their own degree of complexity.

A minor technical point on reflection of the final research question regarding replicability: Although there is clearly an easily defined route for follow-up iterations of the study in which the same primary interviewees are asked (in several years) a similar question on the levels of interaction that they are undertaking. Replicability has not unfortunately been specifically proven within this study since there is no panel data available in relation to the network analysis element of the study. As such, although replicability of study is clearly possible, reliability of response consistency is not proven due to the snap-shot nature (i.e. one timeframe) of the primary findings.

The work has highlighted future research options both in terms of refinement of methodology and enlightenment of the system that could be undertaken to increase our understanding of both. Some of these suggestions are possibly iterative, (such as re-running a simplified network analysis) while others are more original (such as investigating network analysis within different environments or using different proxies for knowledge flows). Either way, they are beyond the scope of this particular research.

References:

Adams Associates UK Ltd (2007) Occupational and Functional Map Renewable Energy Sector. Solihull.

Ahuja, G. (2000) Collaboration Networks, Structural Holes and Innovation: A Longitudinal Study. *Administrative Science Quaterly,* 45**,** 3**,** 425-455.

Airtricity (2007) Building a more powerful Europe. in Airtricity (Ed.). Dublin, Airtricity.

Alchian, A. A. (1950) Uncertainty, Evolution, and Economic Theory. *The Journal of Political Economy,* 58**,** 3**,** 211-221.

Allan, G., Eromenko, I.*, et al.* (2010) The regional electricity generation mix in Scotland: A portfolio selection approach incorporating marine technologies. *Energy Policy,* 39**,** 1**,** 6-22.

Allan, G., Gilmartin, M.*, et al.* (2011) Levelised costs of Wave and Tidal energy in the UK: Cost competitiveness and the importance of "banded" Renewables Obligation Certificates. *Energy Policy,* 39**,** 1**,** 23-39.

Allen, T. & Thomas, A. (Eds.) (2000) *Poverty and Development Into the 21st Century,* Oxford, Oxford University Press.

Anderson, J. C., Håkansson, H.*, et al.* (1994) Dyadic Business Relationships within a Business Network Context. *The Journal of Marketing,* 58**,** 4**,** 1-15.

Arrow, K. J. (1962) The Economic Implications of Learning by Doing *The Review of Economic Studies,* 29**,** 3**,** 155-173.

Arthur, W. B. (1989) Competing Technologies, Increasing Returns, and Lock-In by Historical Events. *The Economic Journal,* 99**,** 394**,** 116-131.

Bahaj, B. & Batten, W. (2005) Job Creation in Europe from Ocean Energy. University of Southampton.

Barrat, A., Barthélemy, M.*, et al.* (2004) The architecture of complex weighted networks. *PNAS,* 101**,** 3747-3752.

BBC (2008) *'Saudi Arabia' of marine energy,* http://news.bbc.co.uk/1/hi/scotland/highlands_and_islands/7676234.stm, 2010, 29th September.

BBC (2011) *Osborne unveils £103m renewables funding for Scotland,* http://www.bbc.co.uk/news/mobile/uk-scotland-highlands-islands-15690682, 2012, 5th of January.

Beaudry, C. & Schiffauerova, A. (2009) Who's right, Marshall or Jacobs? The localization versus urbanization debate. *Research Policy,* 38**,** 2**,** 318-337.

Bergek, A. (2010) Levelling the playing field? The influence of national wind power planning instruments on conflicts of interests in a Swedish county. *Energy Policy,* 38**,** 5**,** 2357-2369.

Bergek, A., Jacobsson, S., *et al.* (2008a) Analysing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy,* 37**,** 407-429.

Bergek, A., Jacobsson, S., *et al.* (2005) Analyzing the Dynamics and Functionality of Sectoral Innovation Systems - A Manual. *DRUID Tenth Anniversary Conference 2005.* Copenhagen.

Bergek, A., Jacobsson, S., *et al.* (2008b) 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems. *Technology Analysis & Strategic Management,* 20**,** 5**,** 575-592.

Bergek, A. & Norrman, C. (2008) Incubator best practice: A framework. *Technovation,* 28**,** 1-2**,** 20-28.

Berkhout, F., Smith, A., *et al.* (2003) Socio-Technological Regimes and Transition Contexts Brighton, Science & Technology Policy Research Unit University of Sussex

BERR, BERR (2008) *UK RENEWABLE ENERGY STRATEGY CONSULTATION.* London; BERR,

Bijker, W. E., Hughes, T. P., *et al.* (1987) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology,* Cambridge. MA, The MIT Press.

BIS (2011a) *Spend over £500 in the Department for Business, Innovation and Skills,* HM Government http://data.gov.uk/dataset/financial-transactions-data-bis, 2011, 10th October.

BIS, vivid economics (2011b) *Economics of the Green Investment Bank.* London;

Black & Veatch, Carbon Trust (2007) *Key Marine Energy Component Technologies for cost Reduction R&D.* London; Carbon Trust,

Boettcher, D. M., Nielsen, N. P., *et al.* (2008) A closer look at the development of wind, wave and tidal energy in the UK. Boston MA.

Bonacich, P. (1987) Power and Centrality: A Family of Measures. *The American Journal of Sociology,* 92**,** 5**,** 1170-1182.

Bonacich, P. & Lloyd, P. (2001) Eigenvector-like measures of centrality for asymmetric relations. *Social Networks,* 23**,** 3**,** 191-201.

Borgatti, S. (1997) Structural Holes: Unpacking Burt's Redundancy Measures. *Connections,* 20**,** 1**,** 35-38.

Braczyk, H.-J., Cooke, P. N., *et al.* (1998) *Regional innovation systems: the role of governances in a globalized world,* London, UCL Press.

Breschi, S. & Malerba, F. (1997) Sectoral innovation systems: technological regimes, Schumpeterian dynamics, and spatial boundaries. in Edquist, C. (Ed.) *Systems of innovation: technologies, organizations, and institutions.* London, Pinter.

British Wind Energy Agency (2006) Path to Power, Delivering Confidence in Britain's Wave and Tidal Stream Industry. London.

Brooke, J. (2003) *Wave Energy Conversion,* Oxford, Elsevier.

Burt, R. S. (1992) *Structural Holes: The social structure of competition,* Cambridge MA, Harvard University Press.

Carbon Trust (2006) Future Marine Energy. in Carbon Trust (Ed.). London, Carbon Trust.

Carbon Trust (2008) Marine Energy Accelerator - Component Technology Strand: ICS-CTS072<076. London.

Carbon Trust (2009a) Focus for Success. London.

Carbon Trust (2009b) Marine Renewables Proving Fund Unlocking the potential of wave and tidal energy. London.

Carbon Trust (2010) *Marine energy ready for mass deployment by 2020,* http://www.carbontrust.co.uk/news/news/press-centre2010/2010/Pages/marine-energy-ready-for-mass-deployment.aspx, 2010, 28th September.

Carbon Trust (2011a) *Who We Are,* http://www.carbontrust.co.uk/about-carbon-trust/who-we-are/pages/default.aspx, 2011, 28th June.

Carbon Trust (2011b) *Resources - conversion factors* 2011 http://www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/carbon-footprinting/pages/conversion-factors.aspx, 2011, 13th of Oct.

Carbon Trust (2011c) Accelerating marine energy. in MEA Report (Ed.). London.

Carbon Trust (2012) *Marine Renewables Commercialisation Fund,* http://www.carbontrust.com/MRCF, 2012, 16th of August.

Carbon Trust & Environmental Change Institute (2005) Variability of UK marine resources. London.

Carlsson, B., Jacobsson, S.*, et al.* (2002) Innovation systems: analytical and methodological issues. *Research Policy,* 31**,** 223-245.

Carlsson, B. & Stankiewicz, R. (1991) On the nature, function and composition of technological systems. *Journal of Evolutionary Economics,* 1**,** 93-118.

Carlsson, B. & Stankiewicz, R. (1995) Nature, function and composition of technological systems. in Carlsson, B. (Ed.) *Technological Systems and Economic Performance: The Case of Factory Automation.* Dordrecht, Kluwer Academic Publishers.

Carrington, P. J., Scott, J.*, et al.* (2005) *Models and Methods in Social Network Analysis,* Cambridge, Cambridge Press.

Chang, Y.-C. & Chen, M.-H. (2003) Comparing approaches to systems of innovation: the knowledge perspective. *Technology in Society,* 26**,** 17-37.

Chesbrough, H., Vanhaverbeke, W.*, et al.* (2006) *Open Innovation Reseaching a New Paradigm,* Oxford, Oxford University Press.

Christopoulos, D. C. (2009) Social Network Analysis Theory and Application 2E. *Essex Summer School in SSDA.* University of Essex.

Clark, J. (2010) *Offshore contractor appointed for Wave Hub,* SWRDA http://www.southwestrda.org.uk/news_and_events/2010/may/offshore_contractor_appointed.aspx, 2011, 7th January.

Cleantech Group (2009) *Pelamis sinks Portugal wave-power project,* http://cleantech.com/news/4276/pelamis-sinks-portugal-wave-power-p.

Coleman, J. S. (1988) Social Capital in the Creation of Human Capital. *The American Journal of Sociology,* 94**,** S95-S120.

Committee on Climate Change, Committee on Climate Change (2011) *Renewable Energy Review Chapter 1 Renewable electricity Generation Scenarios.* London;

Companies House (2011) *WebCheck Service,* Companies House, http://www.companieshouse.gov.uk/, 14th june, 2011.

Connor, P. M. (2003) National Innovation, Industrial Policy and Renewable Energy Technology *British Institute of Energy Economics Conference.* Oxford, UK.

Connor, P. M. (2007) Wave Energy: Going down the Tube? *7th European Wave and Tidal Energy Conference.* Porto, Portugal.

Cooke, P. (1992) Regional innovation systems: Competitive regulation in the new Europe. *Geoforum,* 23**,** 3**,** 365-382.

Cooke, P. (2006) Regional Innovation Systems as Public Goods. in Butler, P. (Ed.). Austria.

Crown Estate (2010a) *Wave and Tidal Pentland Firth and Orkney Waters,* Crown Estate, http://www.thecrownestate.co.uk/energy/wave-and-tidal/pentland-firth-and-orkney-waters/, 2010, 29th September.

Crown Estate (2010b) Map: Pentland Firth and Orkney Waters Round 1 Development Sites. London, Crown Estate,.

Crown Estate (2010c) *Inner Sound Tidal Project Awarded,* Crown Estate, http://www.thecrownestate.co.uk/newscontent/92-inner-sound-tidal-project-awarded.htm, 2011, 24th March.

Crown Estate (2011) *Our portfolio - Round 3 wind farms,* Crown Estate, http://www.thecrownestate.co.uk/round3, 2011, 20th of May.

Dahmen, E. (1950) *Entrepreneurial Activity and the Development of Swedish Industry, 1919-1939,* Nashville, TN, American Economic Association.

Dalton, G. & Ó Gallachóir, B. P. (2010) Building a wave energy policy focusing on innovation, manufacturing and deployment. *Renewable and Sustainable Energy Reviews,* 14**,** 8**,** 2339-2358.

Dalton, G., Rousseau, N.*, et al.* (2009) Non-technical barriers to wave energy development, comparing progress in Ireland and Europe. *8th European Wave and Tidal Conference.* Uppsala, Sweden.

Dalton, G. J. & Lewis, T. (2011) Metrics for measuring job creation by renewable energy technologies, using Ireland as a case study. *Renewable and Sustainable Energy Reviews,* 15**,** 4**,** 2123-2133.

DECC, DECC (2008) *Government Response to the Statutory Consultation on the Renewable Obligation Order 2009.* London; DECC,

DECC, DECC (2009) *The UK Low Carbon Transition Plan.* London;

DECC, DECC (2010a) *Digest of United Kingdom Energy Statistics 2010.* London; Office of national Statistics,

DECC, DECC (2010b) *Marine Energy Action Plan 2010 Executive Summary & Recommendations.* London; HM Government,

DECC.Personal Communication on: 3rd of October 2010c,

DECC, DECC (2011a) *DECC Public Bodies Directory 2009-2010.* London; Crown Copyright,

DECC, DECC (2011b) *UK Renewable Energy Roadmap.* London; Crown Copyright,

DECC (2011c) *MONEY TO MOVE MARINE MACHINES TO MAINSTREAM,* http://www.decc.gov.uk/en/content/cms/news/pn2011_055/pn2011_055.aspx, 2011, 7th of December.

DECC, DECC (2011d) *Planning our electric future a White Paper for secure, affordable and low carbon electricity.* London; The Stationery Office Limited,

DECC (2012a) *RENEWABLE ENERGY TO BRING £25BN OF INVESTMENT INTO UK ECONOMY - DAVEY,* http://www.decc.gov.uk/en/content/cms/news/pn12_086/pn12_086.aspx, 2012, 14th of August.

DECC.Personal Communication on: 23rd of March 2012b,

Desrochers, P. & Sautet, F. (2008) Entrepreneurial Policy: The Case of Regional Specialization vs. Spontaneous Industrial Diversity. *Entrepreneurship: Theory & Practice,* 32**,** 813-832.

Dijkstra, E. W. (1959) A note on two problems in connexion with graphs. *Numerische Mathematik,* 1**,** 1**,** 269-271.

DIUS, DIUS (2008) *Innovation Nation.* Norwich; The Stationery Office Limited,

Dosi, G. (1993) Technological paradigms and technological trajectories : A suggested interpretation of the determinants and directions of technical change. *Research Policy,* 22**,** 2**,** 102-103.

Dosi, G., Freeman, C.*, et al.* (1988) *Technical Change and Economic Theory,* London, Pinter Publishers.

Dosi, G., Marengo, L.*, et al.* (2006a) How much should society fuel the greed of innovators?: On the relations between appropriability, opportunities and rates of innovation. *Research Policy,* 35**,** 8**,** 1110-1121.

Dosi, G., Marengo, L.*, et al.* (2006b) *How much should society fuel the greed of innovators?*

Dosi, G., Orsenigo, L., *et al.* (2002) Technology and the Economy. Pisa, Laboratory of Economics and Management Sant'Anna School of Advanced Studies.

Douglas-Westwood (2008) Wave and Tidal Current Stream activity increasing. Canterbury,, Douglas-Westwood,.

DTI, DTI (2005a) *Wave and Tidal-stream Energy Demonstration Scheme.* London; DTI,

DTI, DTI (2005b) *Response to comments recieved on proposals for the £50M Marine Renewables Deployment Fund May 2005.* London; The Stationary Office,

DTI, DTI (2007) *Meeting the Energy Challenge A White Paper on Energy.* Norwich; The Stationary Office,

Easterby-Smith, M., Lyles, M. A., *et al.* (2008) Inter-Organizational Knowledge Transfer: Current Themes and Future Prospects. *Journal of Management Studies,* 45**,** 4**,** 677-690.

EBSCO Publishing *EBSCO,* EBSCO Publishing, http://web.ebscohost.com/ehost/, 2011, 7th of June.

Edquist, C. (2005) Systems of Innovation Perspectives and Challenges. in Fagerberg, J., *et al.* (Eds.) *The Oxford Handbook of Innovation.* Oxford, Oxford University Press.

EG&S KTN (2010) Funding Opportunities - Marine Renewables. in EG&S KTN (Ed.) *https://ktn.innovateuk.org/web/wave-and-tidal.* EG&S KTN,.

Elsevier (1997) *ScienceDirect,* Elsevier www.sciencedirect.com/, 2011, 7th of June.

emd, South West Regional Employment and Skills Board (2010) *Marine Energy (Wave and Tidal) and Offshore Wind Skills Analysis.*

EMEC (2011) *Site Activity,* EMEC http://www.emec.org.uk/site_activity.asp, 2011, 18th of May.

EMEC (2012) *TIDAL DEVELOPERS,* EMEC http://www.emec.org.uk/marine-energy/tidal-developers/, 2012, 24th of July 2012.

Energy and Climate Change Committee, House of Common (2011) *Electricity Market Reform, Fourth Report.* London; The Stationery Office Limited,

Energy for Sustainable Development Ltd (2004) Offshore Wind Onshore Jobs - A New Industry for Britain. Corsham.

Energy Saving Trust (2008) Crude Oil Price Chronology. *EIA.* London, Energy Saving Trust.

Energy Technologies Institute (2010) Marine Energy Technology Roadmap. in Energy Technologies Institute & UKERC (Eds.). Loughborough.

Energy Technologies Institute (2012) *Marine,* http://www.eti.co.uk/technology_programmes/marine, 2012, 17th of February.

Entec UK Ltd (2009) Marine Renewable Energy State of the industry report – October 2009. London.

EOn *Wave,* EOn http://www.eon-uk.com/generation/wave.aspx#content, 2011, 10th March.

EPSRC (2009) Energy Programme Landscape. in EPSRC (Ed.). Swindon.

Esteban, M., Leary, D*., et al.* (2011) Job retention in the British offshore sector through greening of the North Sea energy industry. *Energy Policy,* 39**,** 3**,** 1543-1551.

Etzkowitz, H. (2001) The Entrepreneurial University and the Emergence of Democratic Corporatism. in Etzkowitz, H. & Leydesdorff, L. (Eds.) *Universities and the Global Knowledge Economy.* London, Continuum.

European Commission (2005) Energy R&D Statistics in the European Research Area. Brussels.

European Marine Energy Centre (2008) *Pathway to EMEC,* www.emec.org.uk/pathway_to.asp, 2009, 29th October.

European Marine Energy Centre (2009a) *EMEC Funding,* European Marine Energy Centre, www.emec.org.uk/general_funders.asp, 2009, 6th Febuary.

European Marine Energy Centre (2009b) *Wave Developers,* http://www.emec.org.uk/wave_energy_developers.asp, 2011, 26th January.

European Ocean Energy Association (2009) Ocean Energy Roadmap - input to the set-plan (Consultation). in European Ocean Energy Association (Ed.). Brussels.

European Ocean Energy Association (2010) Oceans of Energy European Ocean Energy Roadmap. Brussels.

European Patent Office (2010) *Search for European Patent Classification,* http://v3.espacenet.com/eclasrch?classification=ecla&locale=en_EP&ECLA=f03b13, 2010, 18th Febuary.

Everett, M. G. & Bogatti, S. P. (2005) Extending Centrality. in Carrington, P. J*., et al.* (Eds.) *Models and Methods in Social Network Analysis.* Cambridge, Cambridge University Press.

EWEA (2008) Wind at Work. Brussels.

Faber Maunsell & Metoc plc, Scottish Government (2007) *Scottish Marine Renewables Strategic Environmental Assessment Non Technical Summary.* Edinburgh; Scottish Government,,

Fagerberg, J. (2003) Innovation: A Guide to the Litrature. Oslo, University of Oslo.

Fagerberg, J., Mowery, D. C*., et al.* (2005) *The Oxford Handbook of Innovation,* Oxford, Oxford University Press.

Farley, F. (1981) *Wave energy converters*, EPO0035346A2, www.espacenet.com,

Farley, F. (2005) *Flexible beam wave energy converter*, GB2433553A, www.espacenet.com,

Fenn, J. & Linden, A. (2005) *Gartner's Hype Cycle Special Report for 2005,* http://www.gartner.com/DisplayDocument?doc_cd=130115, 2012, 18th January.

Fleck, J. (1994) Learning by trying: the implementation of configurational technology. *Research Policy,* 23**,** 6**,** 637-652.

Fleming, L., III, C. K*., et al.* (2007a) Small Worlds and Regional Innovation. *Organisation Science,* 18**,** 6**,** 938-954.

Fleming, L., Mingo, S., *et al.* (2007b) Collaborative Brokerage, Generative Creativity, and Creative Succes. *Administrative Science Quaterly,* 52**,** 3**,** 443-475.

Foxon, T., Köhler, J., *et al.* (2008) Innovation in energy systems: Learning from economic, institutional and management approaches. in Foxon, T., *et al.* (Eds.) *Innovation for a Low Carbon Economy.* Cheltenham, UK, Edward Elgar.

Foxon, T. J., Gross, R., *et al.* (2005) UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. *Energy Policy,* 33**,** 2123-2137.

Foxon, T. J. & Pearson, P. J. G. (2007) Towards improved policy processes for promoting innovation in renewable electricity technologies in the UK. *Energy Policy,* 35**,** 3**,** 1539-1550.

Freeman, C. (1987) *Technology Policy and Economic Performance: Lessons from Japan,* London, Pinter.

Freeman, C. & Soete, L. (1997) *The Economics of industrial Innovation (3rd Edition),* London, Frances Printer.

Freeman, C. & Soete, L. (2007) Developing science, technology and innovation indicators. What we can learn from the past. UNU-MERIT.

Freeman, L. C. (1978) Centrality in social networks conceptual clarification. *Social Networks,* 1**,** 3**,** 215-239.

Freeman, L. C., Borgatti, S. P., *et al.* (1991) Centrality in valued graphs: A measure of betweenness based on network flow. *Social Networks,* 13**,** 2**,** 141-154.

Future Energy Solutions, Scottish Executive (2002) *Opportunities for marine energy in Scotland.* Edinburgh; Scottish Executive,

Garrad Hassan (2008) Development of Wave Energy in the South West. Bristol.

Geels, F. W. (2004) From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy,* 33**,** 6-7**,** 897-920.

Geels, F. W. (2005) *Technological Transitions and System Innovations A Co-Evolutionary and Socio-Technical Analysis,* Cheltenham, Edward Elgar Publishing Ltd.

GfK NOP Social Research, Department for Trade and Industry (2006) *Renewable Energy Awareness and Attitudes Research 2006.* London;

GfK NOP Social Research, Department for Business Enterprise and Regulatory Reform (2007) *Renewable Energy Awareness and Attitudes Research 2007.* London;

GfK NOP Social Research, Department for Business Enterprise and Regulatory Reform (2008) *Renewable Energy Awareness and Attitudes Research 2008.* London;

GfK NOP Social Research, Department for Energy and Climate Change (2009) *Renewable Energy Awareness and Attitudes Research 2009.* London;

Glaeser, E. L., Kallal, H. D., *et al.* (1992) Growth in Cities. *Journal of Political Economy,* 100**,** 6**,** 1126-1152.

Goodman, L. A. (1961) Snowball Sampling. *The Annals of Mathematical Statistics,* 32**,** 1**,** 148-170.

Gould, R. & Fernandez, R. (1989a) Structures of Mediation: A Formal Approach to Brokerage in Transaction Networks. *Sociological Methodology,* 19**,** 89-126.

Gould, R. V. & Fernandez, R. M. (1989b) Structures of Mediation: A Formal Approach to Brokerage in Transaction Networks. *Sociological Methodology,* 19**,** 89-126.

Granovetter, M. S. (1973) The Strength of Weak Ties. *American Journal of Sociology,* 78**,** 6**,** 1360-1380.

Haas, R., Eichhammer, W., *et al.* (2004) How to promote energy systems successfully and effectively. *Energy Policy,* 32**,** 833-839.

Haas, R., Nakicenovic, N., *et al.* (2008) Towards sustainability of energy systems: A primer on how to apply the concept of energy services to identify necessary trends and policies. *Energy Policy,* 36**,** 4012-4021.

Håkansson, H. (1990) Technological collaboration in industrial networks. *European Management Journal,* 8**,** 3**,** 371-379.

Hamlyn, V. J. (2009) Climate Change Regimes in the Context of Marine Renewable Energy and Some Potential Legal Difficulties Facing Marine Renewable Energy Development in England and Wales. *Plymouth Postgraduate Symposium 2009.* Plymouth, University of Plymouth.

Hanneman, R. A. & Riddle, M. (2005) Introduction to Social Network Methods. Riverside, CA, University of California.

Hansen, M. T. (1999) The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits. *Administrative Science Quarterly,* 44**,** 1**,** 82-111.

Harborne, P. & Hendry, C. (2009) Pathways to commercial wind power in the US, Europe and Japan: The role of demonstration projects and field trials in the innovation process. *Energy Policy,* In Press, Corrected Proof.

Hekkert, M. P. & Negro, S. O. (2009) Functions of innovation systems as a framework to understand sustainable technological change Empirical evidence for earlier claims. *Technology Forecasting and Social Change,* 76**,** 584-594.

Hekkert, M. P., Suurs, R. A. A., *et al.* (2007) Functions of innovation systems A new approach for analysing technological change. *Technological Forecasting & Social Change,* 74**,** 413-432.

Heller, M. (1998a) The tragedy of the anticommons: property in transition from marx to markets. *Harvard Law Review,* 111**,** 698-701.

Heller, M., Eisenberg, R., (1998b) Can patents deter innovation? The anti-commons in biomedical research. *Science and Public Policy,* 280**,** 698-701.

HM Revenue and Customs *Rates of Exchange for Customs and VAT purposes 06-2008,* HM Revenue and Customs, http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageVAT_RatesCodesTools&propertyType=document&id=HMCE_PROD1_028625, 2011, 23rd of March.

Homans, G. C. (1951) *The Human Group,* London, Routledge & Kegan Paul Ltd.

ICCEPT & E4tech Consulting, The Department for Trade and Industry (2003) *The UK Innovation Systems for New and Renewable Energy Technologies.* London; The Department for Trade and Industry,

IEA-OES (2006) Review and analysis of ocean energy systems development and supporting policies. Lisbon.

IEA (2009) ENERGY TECHNOLOGY RD&D BUDGETS DOCUMENTATION FOR BEYOND 2020 FILES. 1 ed. Paris, International Energy Agency.

IEA (2010) *IEA Online R&D Budgets,* http://wds.iea.org/WDS/TableViewer/dimView.aspx?ReportId=1039, 2010, 29th September.

IHS Emerging Energy Research (2010) Global Ocean Energy markets and Strategies 2010-2030. Cambridge MA, IHS Emerging Energy Research.

IPCC (2007a) Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers. in IPCC (Ed.) *IPCC Fourth Assessment Report: Climate Change 2007 (AR4).* Geneva.

IPCC (2007b) Synthesis Report. in IPCC (Ed.) *Climate Change 2007.* Geneva.

Jacobs, J. (1969) *The economy of cities,* London, Vintage Books.

Jacobsson, S. & Johnson, A. (2000) The diffusion of renewable energy technology: an analytical framework and key issues for research. *Energy Policy,* 28**,** 9**,** 625-640.

Jeffery, J. (1990) Dirty Tricks: How the Nuclear Lobby Stopped the Development of Wave Power in Britain. *The Ecologist,* 20**,** 3**,** 85-90.

Jeffrey, H. F. (2007) An Investigation of the Knowledge Base of the UK Marine Renewable Sector. *7th European Wave and Tidal Energy Conference.* Porto, Portugal.

Johnson, A. & Jacobsson, S. (1998) The emergence of a growth industry - a comparative analysis of the German, Dutch and Swedish wind industries. Götenborg, Chalmers University of Technology,.

Johnson, A. & Jacobsson, S. (2002) The Emergence of a Growth Industry. A Comparative Analysis of the German, Dutch and Swedish Wind Turbine industries. *Academy Winter 2002 PhD Conference.* Aalborg, Danish Research Unit for Industrial Dynamics.

Johnson, A. & Jacobsson, S. (2003) The Emergence of a Growth Industry: A Comparative Analysis of the German, Dutch and Swedish Wind Turbine Industries. in Metcalfe, J. S. & Cantner, U. (Eds.) *Change, transformation, and development.* Heidelberg, Physica-Verlag.

Jonard, N. (2009) Innovation Strategies Alliances and Networks Summary. *DIMETIC Strasboug.* Strasboug.

Jørgensen, U. (1995) The Danish Wind-Turbine Story: Technical Solutions to Political Visions? *Managing Technology in Society - The Approach of Constructive Technology Management*, 57-82.

Julien, P. (2009) Strategic Use of patents: An overview. *DIMETIC.* Strasbourg, BETA - Université de Strasbourg.

Karnøe, P. (1990) Technological innovation and industrial organisation in the Danish wind industry. *Entrepreneurship & Regional Development,* 2, 105-123.

Kortum, S. & Lerner, J. (1999) What is behind the recent surge in patenting? *Research Policy,* 28, 1, 1-22.

Krackhardt, D. & Stern, R. N. (1988) Informal Networks and Organisational Crisis An Experimental Simulation. *Social Psychology Quarterly,* 51, 2, 123-140.

Kreab Gavin Anderson (2010) DECC Wave & Tidal – Investor Survey. London, Kreab Gavin Anderson.

Krugman, P. R. (2003) *International Economics: Theory,* Boston, Pearson Education Inc.

Lavender, G.Personal Communication on: 2010,

Law, J. & Bijker, W. E. (1997) *Shaping Technology/building Society: Studies in Sociotechnical Change,* Cambridge, MA, The MIT Press.

LCICG, LCICG (2012) *Technology Innovation Needs Assessment (TINA) Marine Energy.* London; LCICG,,

Leydesdorff, L. (2000) The triple helix: an evolutionary model of innovations. *Research Policy,* 29, 243-255.

Liu, X. & White, S. (2001) Comparing innovation systems: a framework and application to China's transitional context. *Research Policy,* 30, 7, 1091-1114.

Low, M. B. & Abrahamson, E. (1997) Movements, bandwagons, and clones: Industry evolution and the entrepreneurial process. *Journal of Business Venturing,* 12, 6, 435-457.

Lund, P. D. (2006) Effectiveness of policy measures in transforming the energy system. *Energy Policy,* 35, 627-639.

Lundvall, B.-A. (1992) *National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning,* London, Pinter Publishers.

Lundvall, B.-Å. (1985) Product Innovation and User-Producer Interaction. *Industrial Development Research.* Aalborg University Press

Lundvall, B.-Å. (1988) Innovation as an interactive process: from user-producer interaction to the national system iof of innovation. in Dosi, G. (Ed.) *Technology change and economic theory.* London, Pinter Publishing.

Lundvall, B.-Å., Johnson, B.*, et al.* (2002) National systems of production, innovation and competence building. *Research Policy,* 31, 2, 213-231.

Malerba, F. (2002) Sectoral systems of innovation and production. *Research Policy,* 31**,** 2**,** 247-264.

Mankin, J. C., NASA Office of Space Access and Technology (1995) *Technology Readiness Levels.* Washington; NASA,

Mankiw, N. G. (2001) *Principles of Economics (Second Edition),* Orlando, Harcourt College Publishing.

Marshall, A. (1891) *Principles of economics*, Macmillan and co.

Mayntz, R. & Hughes, T. P. (Eds.) (1988) *The Development of Large Technical Systems,* Frankfut, Germany, Campus Verlag.

McAdams, M. (2012) *Westminster backs UK's wave and tidal potential,* http://www.aquamarinepower.com/blog/westminster-backs-uks-wave-and-tidal-potential/, 2012, 14th March.

Merton, R. K. (1968) The Matthew Effect in Science. *Science,* 159**,** 3810**,** 56-63.

Milgram, S. (1967) The Small-World Problem. *Psychology Today,* 1**,** 1**,** 61-67.

Mitchell, C. (2008) *The Political Economy of Sustainable Energy,* Basingstoke, Palgrave MacMillan.

Mitchell, C. & Connor, P. (2004) Renewable energy policy in the UK 1990-2003. *Energy Policy,* 32**,** 17**,** 1935-1947.

Mueller, M. (2009) UKERC Energy Research Landscape Marine Renewable Energy. University of Edinburgh.

narec (2008) *Marine Renewables, Track Record,* narec http://www.narec.co.uk/sectors/marine_renewables/marine_track_record/, 2011, 18th of May.

National Audit Office, National Audit Office (2010) *Government funding for developing renewable energy technologies.* London; National Audit Office,

National Grid Electricity Transmission plc (2011) *British Electricity Trading and Transmission Arrangements,* 2011 http://www.nationalgrid.com/uk/sys_06/default.asp?action=mnch10_2.htm&Node=SYS&Snode=10_2&Exp=Y#British_Electricity_Trading_And_Transmission_Arrangements, 2011, 10th of October.

Negro, S. O. (2007) Dynamics of Technological Innovation Systems The Case of Biomass Energy. *Copernicus Institute for Sustainable Development and Innovation.* Utrecht, Utrecht.

Negro, S. O. & Hekkert, M. P. (2010) Overcoming Typical Failures in the Emergence of Sustainable Innovation Systems - The Need for a New Form of Innovation Policy. Utrecht, Utrecht University.

Nelson, R. R. (1988) Institutions Supporting Technical Change in the United States. in Dosi, G.*, et al.* (Eds.) *Technical Change and Economic Theory.* London, Pinter Publishers.

Nelson, R. R. (1992) National Innovation Systems: A Comparative Analysis. in Edquist, C. & McKelvey, M. (Eds.) *Systems of Innovation: Growth, Competitiveness and Employment.* Cheltenham, Edward Elgar Publishing Ltd.

Nelson, R. R., Peterhansl, A.*, et al.* (2004) Why and how innovations get adopted: a tale of four models. *Industrial and Corporate Change,* 13**,** 5**,** 679-699.

Nelson, R. R. & Winter, S. G. (1982) *An Evolutionary Theory of Economic Change,* Cambridge. MA, The Belknap Press of Harvard University Press.

New and Renewable Energy Centre (2011) *Core Sectors,* New and Renewable Energy Centre http://www.narec.co.uk/corporate/core_sectors/, 2011, 5th of January.

OECD (1994) The Measurement of Scientific and Technological Activities Using Patents as Science and Technology Indicators. Paris.

OECD (1997) National Innovation Systems. Paris.

OECD, (2002) *Frascati Manual PROPOSED STANDARD PRACTICE FOR SURVEYS ON RESEARCH AND EXPERIMENTAL DEVELOPMENT.* Paris; OECD,

OECD, OECD (2005) *Oslo Manual GUIDELINES FOR COLLECTING AND INTERPRETING INNOVATION DATA.* Paris; OECD,

Ofgem (2007) Renewables Obligation Guidance for generators over 50kW. London.

Ofgem (2011) *Climate Change Levy: Renewables Exemption,* Ofgem http://www.ofgem.gov.uk/Sustainability/Environment/cclrenexem/Pages/CCLRenewablesExemption.aspx, 2011, 15th June.

Oil and Gas UK (2010) Economic Report Section 4: Energy Policy and Security of Supply. in Oil and Gas UK (Ed.). Aberdeen.

Oltander, G. & Perez, E. (2005) A survey of the Swedish security industry and an innovation system analysis of the Swedish security sensor industry. *Masters Thesis.* Götenborg, Chalmers University of Technology.

Opsahl, T. (2010) *Closeness centrality in networks with disconnected components,* Tore Opsahl http://toreopsahl.com/2010/03/20/closeness-centrality-in-networks-with-disconnected-components/, 2010, 9th August.

Ordnance Survey (2010) Ordnance Survey, www.ordnancesurvey.co.uk/oswebsite/freefun/geofacts/geo0059.html, 2011, 28th of June.

Pavitt, K. (1999) *Technology, Management and Systems of Innovaiton,* Cheltenham, UK, Edward Elgar.

Pelamis Wave Power Ltd (2011) *Pelamis Projects Submitted to European Bid,* Pelamis Wave Power Ltd, http://www.pelamiswave.com/news/news/96/Pelamis-Projects-Submitted-to-European-Bid, 2012, 23rd of March.

Peter Bacon & Associates (2005) Analysis of the Potential Economic Benefits of Developing Ocean Energy in Ireland. in Peter Bacon & Associates (Ed.).

Poole, M. S., Ven, A. H. V. d*., et al.* (2000) *Organizational Change and Innovation Processes,* Oxford, Oxford University Press.

Porter, M. E. (1990) *The Competitive Advantage of Nations,* New York, Palgrave.

POST, Parliamentary Office Science and Technology (2009) *Marine Renewables.* London; Parliamentary Office Science and Technology, 324

POST, Parliamentary Office Science and Technology (2011) *Marine Planning.* London; Parliamentary Office Science and Technology,

Powell, W. W., Koput, K. W*., et al.* (1996) Interorganizational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology. *Administrative Science Quarterly,* 41**,** 1**,** 116-145.

Pricewaterhouse Coopers LLP, UKCES (2010) *Strategic Skills Needs in the Low Carbon Energy Generation Sector.* Wath-Upon-Dearne; UKCES, Evidence Report 16

Pure Energy Systems Wiki *Directory:Ocean Wave Energy,* http://peswiki.com/index.php/Directory:Ocean_Wave_Energy, 18th May, 2011.

Raven, R. P. J. M., Bosch, S. v. d*., et al.* (2010) Transitions and strategic niche management towards a compentence kit for practicioners. *Int. J. Technology Management,* 51**,** 1**,** 57-74.

Renewables Advisory Board, Renewables Advisory Board (2008) *Marine renewables: current status and implications for R&D funding and the Marine Renewables Deployment Fund.* London; Renewables Advisory Board,, RAB-2007-0182-Final Version

RenewableUK (2009) *BWEA changes name to RenewableUK,* RenewableUK http://www.bwea.com/media/news/articles/pr20091222.html, 2011, 35th of May.

RenewableUK (2010a) RenewableUK Channeling the Energy A Way Forward for the UK Wave & Tidal Industry Towards 2020. London.

RenewableUK (2010b) The Next Step For Marine Energy Industry The View on the Marine Energy Action Plan. London.

RenewableUK (2011) Wave and Tidal Energy in the UK State of the Industry Report. London.

RenewableUK (2012) Marine Energy in the UK State of the Industry Report 2012. London.

Richardson, N. (2009) *£8m Marine Project announced,* Energy Technology institute http://www.energytechnologies.co.uk/Home/news/09-10-30/%C2%A38m_marine_project_announced.aspx, 2009, 2nd December.

Rogers, E. (2003) *Diffusion of Innovation,* New York, NY, Free Press.

Rogers, S., Sedghi, a*., et al.* (2011) Public spending by the UK's central government. *The Guardian.* London, The Guardian.

Rosenberg, N. (1982) *Inside the Black Box: Technology and Economics,* Cambridge, Cambridge University Press.

Ross, D. (2002) *Clive Grove-Palmer Wave energy programme chief who converted from nuclear power,* The Guardian http://www.guardian.co.uk/news/2002/oct/02/guardianobituaries, 2011, 5th of January.

Rothwell, R. (1993) The changing nature of the innovation process. *Technovation,* 13**,** 1**,** 1-2.

Ruhnau, B. (2000) Eigenvector-centrality -- a node-centrality? *Social Networks,* 22**,** 4**,** 357-365.

RWE NPower Renewables *Marine Renewables,* RWE NPower Renewables http://www.rwe.com/web/cms/en/277044/rwe-npower-renewables/technologies/marine-technologies/, 2011, 10th March.

RWE NPower Renewables (2007) Siadar Wave Energy Project, Isle of Lewis. *BWEA29.* Glasgow.

Ryan, B. & Gross, N. C. (1943) The diffusion of hybrid seed corn in two Iowa communities. *Rural Sociology,* 8**,** 1**,** 15-24.

Salganik, M. J. & Heckathorn, D. D. (2004) Sampling and Estimation in Hidden Populations Using Respondent-Driven Sampling. *Sociological Methodology,* 34**,** 193-239.

Salter, S. (2008) Looking Back. in Cruz, J. (Ed.) *Ocean Wave Energy: Current Status and Future Perspectives.* Berlin, Springer-Verlag.

Salter, S. (2009) Correcting the Under-estimate of the Tidal-Stream Resource of the Pentland Firth. *8th European Wave and Tidal* Uppsala, EWTEC.

Sandén, B. A. & Azar, C. (2005) Near-term technology policies for long-term climate targets--economy wide versus technology specific approaches. *Energy Policy,* 33**,** 12**,** 1557-1576.

Schmookler, J. (1966) *Invention and Economic Growth,* Cambridge, MA, Harvard University Press.

Schumpeter, J. (1934) *The Theory of Economic Development,* Cambridge, Mass., Harvard University Press.

Schumpeter, J. A. (1947) The Creative Response in Economic History. *The Journal of Economic History,* 7**,** 2**,** 149-159.

Scitovsky, T. (1954) Two Concepts of External Economies. *The Journal of Political Economy,* 62**,** 2**,** 143-151.

Scott, J. (2009) *Social Network Analysis A Handbook,* London, SAGE.

Scottish and Southern Energy *Marine,* Scottish and Southern Energy, http://www.sserenewables.com/what-we-do/marine/, 2011, 10th March.

Scottish Enterprise (2012) *Proof of Concept Programme,* http://www.scottish-enterprise.com/start-your-business/proof-of-concept-programme.aspx, 2012, 27th March.

Scottish Government (2009a) Consent document for Siadar Wave Energy Generating Scheme. in Government, S. (Ed.). Edinburgh, Scottish Government.

Scottish Government (2009b) *Marine Energy Policy Statement,* Scottish Government, http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Energy-sources/19185/17853-1/MEPS, 2011, 10th March 2010.

Scottish Government (2009c) *Wave and Tidal Energy Support Scheme FUNDING,* http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Energy-sources/19185/20805/WTSupportScheme/WTSupportSchemeFunding, 2010, 27th September.

Scottish Government (2010a) *Marine energy making a splash,* Scottish Government, http://www.scotland.gov.uk/News/Releases/2010/07/06095653, 2010, 10th October.

Scottish Government, (2010b) *Marine Energy Road Map.* Edinburgh;

Scottish Government.Personal Communication on: 22nd December 2010c,

Scottish Power Renewables *Marine,* http://www.scottishpowerrenewables.com/pages/marine.asp, 2011, 10th March.

Seidman, S. B. & Foster, B. L. (1978) A Graph-theoretic Generalization of the Clique Concept. *Journal of Mathematical Sociology,* 6**,** 139-154.

Shan, W., Gordon, W.*, et al.* (1994) Interfirm Cooperation and Startup Innovation in the Biotechnology Industry. *Strategic Management Journal,* 15**,** 5**,** 387-394.

Shum, K. L. & Watanabe, C. (2009) An innovation management approach for renewable energy deployment--the case of solar photovoltaic (PV) technology. *Energy Policy,* In Press, Corrected Proof.

Simon, H. (1957) *Models of Man: social and rational; mathematical essays on rational human behavior in society setting,* Chichester, Wiley.

Sinclair Knight Merz (2008) Quantification of Constraints on the Growth of UK Renewable Generating Capacity. Newcastle upon Tyne.

Smith, A. (2007) Emerging in between: The multi-level governance of renewable energy in the English regions. *Energy Policy,* 35**,** 6266-6280.

Smith, A., Stirling, A.*, et al.* (2005) The governance of sustainable socio-technical transitions. *Research Policy,* 34**,** 10**,** 1491-1510.

Social Research & Regeneration Unit (2003) Skills Needs of the Marine & Maritime Sector in the South West of England. Plymouth, University of Plymouth.

SPRU (1999) Evaluation of the DTI New and Renewable Energy Programme 1994-8 FINAL REPORT. Brighton, University of Sussex.

SQW Energy (2008) Today's investment tomorrows asset skills and employment in the Wind, Wave and Tidal sectors. London.

Stallard, T., Harrison, G. P.*, et al.* (2009) Economic Assessment of Marine Energy Schemes. *8th European Wave and Tidal Energy Conference.* Uppsala, Sweden.

SWRDA (2009) *£10m boost for South West marine energy research,* http://www.southwestrda.org.uk/news/release.asp?releaseid=3019, 2009, 9th December.

Technology Strategy Board (2010) Technology Strategy Board Driving Innovaiton Press release 23 July 2010. Swindon, Technology Strategy Board.

Technology Strategy Board (2011) *Further investment will quicken pace of innovation in wave and tidal stream energy technologies,* Technology Strategy Board, http://www.innovateuk.org/content/competition-announcements/further-investment-will-quicken-pace-of-innovation.ashx, 2011, 24th of March.

The Danish Wind Industry Association (2010) *The Danish wind industry had a 5.7 billion Euros export in 2008,* http://guidedtour.windpower.org/composite-2287.htm, 2010, 29th September.

The National Archives (2010) *The Department of Trade and Industry (1983-2007),* http://webarchive.nationalarchives.gov.uk/20100216092443/http://www.berr.gov.uk/aboutus/corporate/history/outlines/DTI-1983-onwards/page13934.html, 2011, 30th of June.

The Offshore Valuation Group (2010) The Offshore Valuation. Machynlleth

The Science and Technology Committee, The Science and Technology Committee (2001) *Science and Technology - Seventh Report: Wave and Tidal Energy.* London; The Science and Technology Committee Publications,

Thomas, G. (2008) The Theory Behind the Conversion of Ocean Wave Energy. in Cruz, J. (Ed.) *Ocean Wave Energy: Current Status and Future Perspectives.* Berlin, Springer-Verlag.

Thomson Reuters (2002) *Web of Knowledge,* Thomson Reuters, apps.isiknowledge.com, 2011, 7th of June.

Thomson Reuters (2011) *THE THOMSON REUTERS IMPACT FACTOR,* Thomson Reuters, http://thomsonreuters.com/products_services/science/free/essays/impact_factor/, 2011, 7th of June.

Thorpe, T. W. (1999) *An Overview of Wave Energy Technologies: Status, Performance and Costs,* Bury St. Edmunds, Professional Engineering Publishing Limited.

TNS (2003) Attitudes and Knowledge of Renewable Energy amongst the General Public. London.

Trafalgar Marine Technology Limited.Personal Communication on: 13th of July 2010,

Trident Energy Ltd.Personal Communication on: 19th July 2010,

Tsai, W. (2000) Social Capital, Strategic Relatedness and the Formation of Intraorganizational Linkages. *Strategic Management Journal,* 21**,** 9**,** 925-939.

Tsai, W. (2001) Knowledge Transfer in Intraorganizational Networks: Effects of Network Position and Absorptive Capacity on Business Unit Innovation and Performance. *The Academy of Management Journal,* 44**,** 5**,** 996-1004.

UK Government (1998a) Scotland Act 1998, *Schedule 5, Reserved Matters*. London, Her Majesty's Stationery Office.

UK Government (1998b) Regional Development Agencies Act 1998, *Part 1 S4, Purposes*. London, Her Majesty's Stationery Office.

UK Government (2002) The Renewable Obligation Order 2002. *914.* London, The Stationery Office.

UK Government (2006) Government of Wales Act 2006, *Schedule 5 Part 1, Matters*. London, Her Majesty's Stationery Office.

UK Government (2009a) The Renewables Obligation Order 2009. *785.* London, The Stationary Office.

UK Government (2009b) The Marine and Coastal Access Act 2009. *11/2009 439546 1958.* United Kingdom, The Stationary Office.

United Nations (1982a) United Nations Convention on the Law of the Sea, Section VI, Article 76. United Nations,.

United Nations (1982b) United Nations Convention on the Law of the Sea, Section V, Article 56. United Nations,.

United States Patent and Trademarking Office (2010) *CLASS 405,HYDRAULIC AND EARTH ENGINEERING,* USPC http://www.uspto.gov/web/patents/classification/uspc405/defs405.htm#C405S076000, 2011, 13th January.

Valente, T. W. (2005) Network Models and Methods for Studying the Diffusion of Innovations. in Carrington, P. M.*, et al.* (Eds.) *Models and Methods in Social Networking Analysis.* Cambridge, Cambridge University Press.

Vantoch-Wood, A., Groot, J. d.*, et al.* (2012) National Policy Framework for Marine Renewable Energy within the United Kingdom. *WP4 from the MERiFIC Project.* Penryn, MERiFIC.

Walker, G., Bruce, K.*, et al.* (1997) Social Capital, Structural Holes and the Formation of an Industry Network. *Organization Science,* 8**,** 2**,** 109-125.

Walter, D. (2010) Wave & Tidal Energy The Investor Perspective. *Renewable UK: Wave and Tidal 2010.* London, Kreab Gavin Anderson.

Wasserman, S. & Faust, K. (1994) *Social network analysis: methods and applications,* Cambridge, Cambridge University Press.

Wasserman, S., Scott, J.*, et al.* (2005) Introduction. in Carrington, P. J.*, et al.* (Eds.) *Models and Methods in Social Network Analysis.* Cambridge, Cambridge University Press.

Watanabe, K. (1986) *Wave power generating apparatus of air-circulating type*, GB19850009332, www.espacenet.com,

Watson, J. (2008) Setting Priorities in Energy Innovation Policy: Lessons for the UK. Cambridge, Mass., Belfer Center for Science and International Affairs.

Watts, D. J. (1999) *The Dynamics of Networks: Socioeconomic Models of Production,* Princeton, Princeton University Press.

Watts, D. J. & Strogatz, S. H. (1998) Collective dynamics of ‘small-world’ networks. *Nature,* 393**,** 440-442.

Wave Hub (2011) *Wave Hub Project History,* http://www.wavehub.co.uk/about/project-history/, 2011, 12th of October.

Wavenet (2003) Results from the work of the European Thematic Network on Wave Energy.

Waveplam (2009) State of the Art Analysis. in Hydraulic & Maritime Research Centre- University College Cork (Ed.). Cork, Waveplam.

Webb, T. (2010) *Oil lobby in legal threat to North Sea wind farms,* The Observer http://www.guardian.co.uk/business/2010/oct/31/oil-industry-wind-farm-threat, 2011, 26th of May.

Welsh Assembly Government, Welsh Assembly Government (2009) *Ministerial Policy Statement on Marine Energy in Wales.* Cardiff; Welsh Assembly Government,,

Welsh Assembly Government, Welsh Assembly Government (2010) *The Welsh Assembly Government Energy Policy Statement.* Cardiff; Crown Copyright,

Wene, C.-O. (2008) A cybernetic perspective on technology learning. in Foxon, T. J.*, et al.* (Eds.) *Innovaiton for a Low Carbon Economy.* Cheltenham, Edward Elgar.

West, J., Bailey, I.*, et al.* (2009) Stakeholder Perceptions of the Wave Hub Development in Cornwall, UK. *8th European Wave and Tidal Energy Conference.* Uppsala, Sweden.

Winskel, M., McLeod, A.*, et al.* (2006) Energy policy and institutional context: marine energy innovation systems. *Science and Public Policy,* 33**,** 5**,** 365-376.

Witkamp, M. J., Raven, R. P. J. M.*, et al.* (2011) Strategic niche management of social innovation the case of social entrepreneurship. *Technology Analysis & Strategic Management,* 23**,** 6**,** 667-681.

Woodman, B. & Mitchell, C. (2011) Learning from experience? The development of the Renewables Obligation in England and Wales 2002–2010. *Energy Policy,* 39**,** 7**,** 3914-3921.

World International Patent Office (2010) *Classifications,* WIPO http://www.wipo.int/classifications/ipc/ipc8/?lang=en, 2010, 13th April.

World International Patent Office & UNESCO (2009) Number of Resident Patent Filings per $Million Research & Development (R&D) Expenditure. Geneva.

Yemm, R. W. & Henderson, R. M. (2011) *Apparatus for Extracting Power From Waves*, WO2011/061546A2, www.espacenet,