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‘An exploration of the drivers and indicators of emergence in the Offshore Wind Power industry’

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Declaration of authenticity and author's rights

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date: 5th June 2020

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Abstract

The emergence of new industries is a rare but critical part of the development and growth of any economy. Successive governments have attempted to nurture the development of specific new industries with mixed success – some industries emerge only to disappear after a short time.

There is a substantial body of literature which looks at specific aspects of the phenomenon of industry emergence from within the evolutionary economics and business management domains. This body of knowledge is focused on mass-manufacturing industry and constrained by a post-hoc nature of empirical studies to date.

This is the first research to study an industry during its emergence and in doing so addresses a limitation of the existing research identified by authors in the field. The selected industry, Offshore Wind Power, is a complex product system industry thereby helping to extend the existing knowledge base from its previous mass-manufacture focus. This research seeks to address the applicability of mass manufacture focussed research to a complex product system industry, and to gain additional insights through observing emergence 'as it happens'.

The research is therefore exploratory in nature and is guided by the existing literature on drivers and indicators of emergence. The research shows that certain indicators of emergence (e.g. dominant design, accelerating sales growth) are not applicable in this industry and that some drivers and indicators are linked in causal loops – e.g. growth and legitimacy.

This research uses a 'systems lens' to synthesise an understanding of how the various single factors previously researched interact. This systems approach leads to a proposed framework for industry interaction to promote both emergence and viability. This framework is tested against a recent counter case of a complex product system industry that has not reached emergence and the utility of the framework demonstrated.

1. Introduction

1.1 The Bigger Picture

At the time of writing the world economy is just emerging from the grip of a recession comparable to the worst depressions of the 20th century lasting for over 8 years. The press blames the crisis on the financial services industry and in the UK (an economy heavily reliant upon this industry) there has been a cross party consensus on the need to re-balance the economy with more contribution to GDP coming from manufacturing.

At the same time, there has been a successful drive to increase the capability of the UK economy to provide its energy requirements from renewable resources (primarily through on-shore wind). This development has been led by a mix of UK and European organisations but the primary equipment manufacturers have been non-UK and this is considered to have been a missed opportunity for UK manufacturing industry (see Foxon et al, 2005).

While there is still capacity to be developed in on-shore, offshore wind is being looked at as a long-term commercial opportunity. The UK is well placed to make use of offshore wind, with a high level of potential wind resource and existing expertise in engineered offshore installations from the Oil and Gas industry (Greenacre et al, 2010). The first 10 years of this industry (2000 - 2010) saw the UK take a lead in offshore wind power with more installed capacity than the rest of the world put together. However there are formidable technical challenges in making investment in offshore wind provide a positive return to the country as it moves from a feasibility demonstration stage to full commercial viability.

The political desire to increase the manufactured element of GDP, the large economic and environmental potential of offshore wind, the UK’s leading position in existing offshore wind installation and the engineering expertise from the Oil and Gas industry are strong drivers to deliver a new industry for the UK.

This new industrial age is not guaranteed. There are almost as many forces acting against the growth of a UK based offshore wind industry e.g. questions over the affordability of the offshore wind subsidy, questions of offshore winds technical maturity compared to alternative low-carbon energy sources (e.g. nuclear), the availability of skills (Oil and Gas is not sitting around with spare capacity – in fact quite the reverse), the impact on the grid of large scale inputs from less continuous energy sources and the public acceptability of offshore wind installations.

The solution to balance these competing forces lies in an industry system that generates sufficient returns (financial and other e.g. reduced carbon production) to sustain itself in the longer term and has sufficient capacity and capability to adapt to an uncertain future. The necessary component to create such an industry is the focus of this research.

1.2 Context of new industry creation

1.2.1 What new industries have started since 1988?

The creation, or emergence, of new industries is not a common occurrence and the identity of new industries can often be argued e.g. will electric vehicles constitute a new industry or just a new offering within the motor industry?

To demonstrate both the scarcity of new industry emergence, and the issues of identifying such industries the following list was assembled for new industries which can be considered to have emerged between 1988 and 2018. This 30 year timescale is somewhat arbitrary but can be seen as a ‘generation’ level period. The list is not intended to be an exhaustive list but input was sought from colleagues and contacts to ensure major new industries were identified.

Personal computers

Whilst the small home computer had existed for some time prior to 1988, the computers (Commodore64s, BBC micros etc.) had been the provenance of hobbyists rather than a general use of computing by the general public. The arrival of the Apple Macintosh in the early 80’s and the IBM PC (and clones) loaded with Windows 3 in the late 80’s saw the PC become ubiquitous, and the industry emerge. It is a matter of debate whether it was a technical discontinuity that triggered the emergence, and whether that technical discontinuity was hardware or software.

By 2018, the industry has become highly fragmented with many competing solutions to personal computing needs – from laptops and tablets to ‘cloud’ enabled devices (Chromebooks) and smart phones, few of which look anything like the original desktop PC.

Electronic Gaming

This can be seen as related to the PC industry but is a separate industry. The growth of integrated circuit electronics (a technology discontinuity) has enabled a large number of new market offerings that either transformed existing industries (e.g. television and home recording) or were established as industries before the arbitrary start date. Electronic gaming grew into an industry from a number of directions (as is further discussed in the literature review) – the moving of arcade titles to PCs (Atari, Sega etc.), the development of consoles (Sega, Nintendo and Sony) and the coding of new offerings to work across platforms (Doom being an early example).

Mobile Telephony

The mobile phone industry in the UK grew out of a mixture of ‘market discontinuity’ (changes to the control of transmission frequencies and equipment) and ‘technology discontinuity’ (cellular mobile technology. The first UK provider was Vodafone in 1985, with new services providers coming into the market from that date. The market took off when the product technology led to genuinely portable devices and service innovation (monthly contracts etc.) made them affordable.

As an overall industry there have been a number of step changes driven by market and technology change (e.g. 2G, 3G, 4G cellular technology, smartphones). There is a trend towards blurred boundaries between this industry and those of PCs and gaming. As the delivery device takes less importance than the service being delivered.

Financial Services

The financial services industry is arguably another industry which emerged in the period set. It has grown as a result of the ‘Market discontinuity’ of deregulation around financial services which can be seen as starting with the ‘big bang’ of deregulation of the London stock market in 1986. The industry has grown through innovation in service offerings and from the continually changing format of regulation.

The complexity of the innovative financial instruments (e.g. Credit Default Swaps) and the failure to properly understand their risks is often credited with causing the financial crash.

Online Retail

The growth of online retail started in the 90’s with Amazon taking advantage of the technology discontinuity of the internet and browser technology, and the collapse of the net book agreement in the mid 90’s as a market discontinuity to sell books and CDs cheaply. The UK Office for National Statistics identified that by 2018, 18% of all retail sales were online with strong growth still being shown (15% in the year to July 2018).

Such sales cover everything from media and electronics to food, fashion and pharmaceuticals. It is not clear where the final division between online and 'bricks and mortar' sales will come.

'Renewables' energy generation

As with the earlier examples, the roots of this industry can be traced to before the arbitrary start date of 1988. Most of the hydro-power generation in the UK dates far before this, indeed it could be argued to be the earliest energy source (from waterwheels powering the earliest textile looms). Similarly nuclear power's construction stage was largely before 1988 and wind and solar photo-voltaic all have antecedents.

What is argued here is that it was the 'market discontinuity' of looking for power generation that does not emit greenhouse gases, required of states by the 1992 Kyoto Protocol, that has led to a new industry within the chosen timescale. This industry has a number of different segments that can be argued to be their own industry, from household SolarPV to small scale hydro-power to onshore wind farms. Of all the industry segments, it only onshore wind had reached a significant share of the energy generation market at the time of commencing the research. The lack of a UK manufacturing base for this industry is one of the motivations behind this research.

Future Importance

With only 6 examples and at least 4 of them being closely related (PC's, gaming, mobile telephony and online retailing all grew from the technical discontinuity in electronics and computing), the rarity of new industry emergence can be seen.

It might be argued that this low frequency means that the phenomenon has low importance. The counter argument is that the low frequency means that there is a need to build understanding from each case. The financial and societal impacts of the examples identified have been transformational. It can be argued that better gestation of a new industry gives more resilience to an economy, or more negatively, failure to bring new industries to fruition will have a detrimental effect to a given economy. The literature review will touch upon the Chinese state-capitalism identification of strategic emerging industries as a driver for that economy (e.g Hu and Philips, 2011; Xiaohua and Feng, 2013).

With market and technical discontinuities being the seed points for the emergence of new industry, the continuing change in global markets (not only increasing openness via World Trade Organisation rules and multi-party trade agreements, but also increasing protectionism in the largest nations economy) and the ongoing pace of change in technologies suggests that new industry emergence is likely to be more frequent in future. The following candidates for future industries can be rapidly identified:

- Internet of Things (IoT) driven industry: There are many technological candidates for the driver of the forth wave of industry productivity of which IoT is perhaps the most visible.
- Circular economy product service system industries: Business to business industries are already emerging as product – service systems (Rolls Royce ‘power by the hour’ being an often cited example). The same drivers that exist for low carbon power generation drive the need for low resource use products. The circular economy movement brings these trends together to offer a very different vision of product industry.
- Mobility as a service: The trends in electrification of transport, development of autonomous driving technologies, increasing servitisation of personal cars (lease deals including servicing, services at home etc) are expected to lead to business models where transport is available on demand.
- Commercial space flight: The successful drive of Space exploration Technologies (SpaceX) to significantly reduce launch costs is already having an impact on satellite manufacture. The wider ramifications of the new starts encouraged by this success are yet to be seen.

1.2.2 Specific case of Offshore Wind Power

The case of offshore wind power has a number of features that make it of particular interest to research and understand. It is a stated goal of the SNP - led Scottish Government for Scotland to be a leader in offshore wind power. This goal is reinforced by the political balance where the SNP is a minority government supported by the green party who wish to see a decarbonised economy. The support for this aim is less clear from the UK government where different parties have different views on the topic – from the Labour party who have been supportive, through the Liberals and on to the Conservatives who have been at least sceptical about the opportunity.

The level of offshore wind resource available to the UK in general, and Scotland in particular, is high compared to the rest of Europe and so there are location benefits to developments in UK waters that align with regional policy goals (if not national).

A third aspect of the potential industry that makes it an attractive subject for study is the substantial economic benefit that is expected from the industry. This comes from both the large investment demanded by it (estimates of the total investment range greatly but are in the £30B to £100B range by 2030) and the ongoing need for operations and maintenance for at least 30 years (again there are a range of estimates between £700M to £1,400M annually). This is in contrast to other emerging industries where the benefit comes mostly during the construction phase, and there is no easily forecasted ongoing benefit.

It is not only the financial outcomes of the activity that will bring benefit. There is also an environmental benefit in the reductions in CO_2 emissions from electricity generation that the technology provides. This fourth aspects is, at least initially, a significant driver for the technology. At the start of the research the only foreseeable financial returns for investment in offshore wind power came from subsidy for low carbon generation. This support cannot be taken for granted.

A final aspect of the situation that makes it attractive for research is that it affords the rare opportunity to do a longitudinal study on an industry during its emergence. As will be shown in the literature review, existing studies of emergent industry are done 'post-hoc'. The reasons why are explored later, but at least in part it is a high risk strategy to follow an industry before its final outcome is known. It will be argued later that the combination of rarity of opportunity and positive drivers for the industry reduced this risk. In the end even a negative outcome for the nascent industry would afford the opportunity for beneficial research outcomes.

1.3 Research Aims and Objectives

The start point for this thesis came from a consideration of the increasing interest and activity in offshore wind power and of the relative rarity of new industry emergence that led to the naive question;

'How do we create a sustainable industry for offshore wind power?'

The desire to be able to answer such a question comes from the history of 'boom and bust' support of industries in the past – an example would be that of 'Silicon Glen' which during this author's undergraduate career was touted as the high-tech, knowledge-based industry that would naturally replace the old smoke stack industries such as ship building and steel making. Today there are still a few companies involved in electronics production, just as there are a few in commercial ship building and in steel making.

A counter example in the same timescale is North Sea oil and gas. This industry started before the cut off date used above in selecting examples and is roughly contemporary with Silicon Glen. In the early years it was widely predicted to have a short life span and in 1985 did not look like a long term prospect to a newly graduated engineer. The size of the industry in Scotland is still growing in 2018, in part because the majority of its work is not now North Sea based. With new fields still being brought into production, and decommissioning now being tackled it is likely to remain an significant employer for another 30 years.

It is tempting to decry the lack of capability of forebears in managing industrial change but a deconstruction of the naive question above highlights underlying complexity in the implicit goal.

What is an industry?

The initial question set above cannot get very far if there is no clear definition of what an industry is, but it is not a straightforward entity to define. Indeed the background research and literature on the definition of an industry forms part of the literature review in the next chapter. This shows that the frequently used definition for industry – the Standard Industry Classification (SIC) codes used by national statistic bodies for data gathering and reporting – fails to cover all the entities involved in the emergence of an industry and that during industry emergence the identity of the industry is poorly served by SIC codes – a new industry doesn't have a unique code until it has reached a level of general recognition (although this may fall short of industry emergence).

The literature review will also show that there is substantial conflation between the definition of industry, the territory it operates in and the markets it serves. This conflation can be demonstrated by considering the automotive industry. This is a readily recognised, global industry in which the producers inevitably operate in multiple territories and markets and yet we talk about the UK car industry. There are recognisable markets with differing demands – usually taken in some division of European, North American, Asian and Rest of World markets; but do these signify different industries? Today it is arguably a single industry, with some regional geographic variation (e.g. Kei cars in Japan). This is not a permanent feature, and local legislation can change it.

Similarly one can look at newer industries and find the same difficulty in unpicking industry from markets and geographic territories. For example is the social media industry in China a different industry from that in North America?

A background aim for this research then is to demonstrate a definition of industry that supports research into emerging industries without ambiguities around markets and territories or subjective choices on the part of the researcher.

What do we mean by sustainable?

The term 'sustainable' in the question above relates to ability of the industry to continue. Whilst this is not a different meaning to the way the word 'sustainable' is currently used, it is not intended to convey the same environmental connotations.

The focus, then, is on the ability of the industry to continue rather than its ability to use resources that does not diminish the availability of such resources for future use (the Brundtland commission definition, Brundtland et al,1987). To differentiate between these alternatives the term 'viability' is used to describe this ability to continue at a given point in time.

This leaves open the question of how an industry may be assessed for its 'viability'. The more general definition of 'viability' is more problematic. The assessor must first determine a time horizon over which the ability is assessed and then consider what indicators there may be for an ability to continue (or otherwise) through to this time horizon. As with definitions of industry this research will require an objective measure of 'viability' to fully address the question set.

What does creation mean in the context of something as complex as an industry?

The third definitional element of the question relates to the 'creation' of an industry. As has been indicated above, industries are seen to grow out of some form of technology or market discontinuity. One can create the discontinuity, but that is not the same as creating the industry.

There is consideration to be given regarding the 'creation' of an entity versus the conscious involvement in the 'evolution' of that entity over time. This also brings in the question of the identity of the 'we' in the context of industry creation.

The aspects that will be considered are the ways in which interested parties engage to further the future of an industry. This may be through:

- Strategic investment e.g. by companies diversifying into the industry
- Acceleration of some aspect e.g. building infrastructure in advance of the demand
- De-risking of some aspect e.g. through research and development support

Why create a new industry?

As a final element of considering the initial question one can consider the motivation behind creating a new industry. There is a free market view that one doesn't have to do anything as new industries will just emerge as a result of PESTEL type change. A counter to such arguments is that a laissez-faire approach requires a very large host economic system and a capacity to support many failed experiments.

There is a strong argument that a capability to support new industries is important for a nation that aims to sustain or improve the economic well-being of all its citizens when rapid change is occurring globally. This need not be as a result of grand visions for global competitiveness but may simply be the natural outcome of policy considerations e.g. the need to replace declining industry or a desire to take advantage of promising new technology. This latter point is exemplified by the Chinese government's identification of 'Strategic Emerging Industries' that its state capitalism system intends to foster (Xiaohua and Feng, 2013).

The initial discussion on the limited examples of emerged industries in a 30 year period does beg the question of whether the UK economic system is any good at creating new industries. The experience of Silicon Glen would suggest not, but this could be countered by success in Financial Services and Gaming. There is also a valid question of what does good look like? This may be the number of new jobs created (compared to the cost of investment), the Gross Value Added to the economy as a whole, or the number of new companies created.

The final answer to why one should aim to develop this capability may lie in the observed success of other countries in supporting new industries, and the need to remain competitive in the global economy.

The complexity of the question also highlights the need for the research to be 'Mode 2' (after Gibbons, 1994) – the question needs exploration from a number of differing theoretical positions, and the intent is to lead to a practical tool or framework.

1.3.1 Research Aim

The broad aim of this research then is to understand industry emergence as it relates to Offshore Wind Power (OWP) to better support emergence of future industries.

This may include ways that external agencies can interact with such an industry to;

- accelerate the rate of emergence / reduce the time to achieve emergence
- increase the ability of the industry to continue for a foreseeable future
- optimise the use of resources to achieve this

The original question can be restated as:

What can involved agencies do to support the emergence of viable new industries?

1.3.2 Research Objectives

The research aim can be broken down into a number of more concrete research objectives that will lead towards the achievement of the end goal.

Understand how the OWP industry's emergence relates to existing theory

As will be explored in the literature review, the existing knowledge on the drivers and indicators of emerging industries is based on the post-hoc analysis of mass-manufacture industries. The emergence of Complex Product Systems industries has not been investigated, but comparisons between other aspects of mass manufacture and complex product system industries (e.g. resource capabilities) suggest that differences can be anticipated.

Understand interaction of factors during emergence

Prior studies on the emergence of industries have focussed on the impact of individual drivers across a range of industries. Observation of an industry during its emergence offers the opportunity to understand whether and / or how the multiple drivers of emergence interact to impact on the emergence of the industry.

Assessing indicators of emergence and viability during emergence

The identification of emerged industries is a trivial matter once the industry is established. This research will look at how the state of emergence can be assessed during the industry's emergence – whether existing indicators provide clear information, or whether alternate indicators are required. Of particular interest is whether the industry's ongoing future (viability) can be assessed.

1.4 Research Questions

The following formal research questions are used to direct the research towards the achievement of the above aims and objectives.

1.4.1 RQ1 Does OWP follow the pattern of emergence identified in the literature?

This question investigates the relevance of existing theory (built on mass manufacturing industries) to a complex product system industry. The existing theory can be tested via the applicability of the drivers for emergence and the indicators of emergence in this case.

1.4.2 RQ2 What can be learned from the observation of an industry during its emergence?

Prior investigations of emerging industries have been undertaken after the industries' emergence, based on the recorded data from the emergence stage. The observation of an industry during its emergence offers the opportunity to build a richer picture of the phenomenon – from the reaction of individuals and organisations to policy to the way individual drivers for emergence interact.

1.5 Layout of the Thesis

This section outlines the layout of the thesis, starting with this introduction chapter which sets out the initial motivation for the research and explores the background of the topic to set it in context.

An exploration of the key elements of the question leads to the underlying aims for the research and a stating of the research questions which will be more fully explored in chapter 3.

The literature review chapter leads on from the introduction to explore what is already known about the creation and emergence of new industries. Following an explanation of the methodology used in the review of the literature, the chapter follows two strands of investigation for new industry emergence.

In the first part a review is made of three domains of underpinning theory – economics, business management and systems thinking. The first 2 domains (economics and business management) are explored for concepts, frameworks and tools that may help meet the stated aims and objectives of the research via a structured methodology which is explained in the chapter. This initial works suggests the third domain of systems thinking as also relevant and useful.

The second part of the literature review is an exploration of recent existing case studies of industry emergence. These case studies are based in a variety of research domains (highlighting the need for a ‘mode 2’ approach to the literature) and follow a variety of methodologies to reach their conclusions. The review of this research re-iterates the two core domains of theoretical knowledge that are used to investigate the cases, and are revised in the light of the case findings. These are broadly described as the domains of evolutionary economics and business management.

The case papers also allude to the relevance of systems understanding of the phenomena being investigated in cases looking at the whole industry behaviour. This suggests the relevance of the third domain of theory in systems thinking.

The chapter closes with a summary of the gaps in the research that will underpin the research questions explored in chapter 3 – Methodology.

The methodology chapter sets out the rationale for the research design followed in this investigation. This starts from a clear stating of the aims, objectives and research questions that the study will address. The nature of research design and the decisions that the researcher must make in finalising the research design are then explored to demonstrate the choices are fully understood. This critical appreciation of the choices is a core element of ensuring the validity of the final findings.

Following this critical review an exposition of the research paradigm chosen for this study is made. The paradigm addresses the challenging ontological and epistemological nature of systems enquiry and explains why the final decision of a qualitative ontology and critical realist / interpretivist epistemology was taken by the researcher. These decisions lead towards the case study methodology used and the particular detail choices of this methodology are explained next. The critical review of the research paradigm closes with a discussion of the case selection. This section addresses the implications of a single case research design.

The remaining elements of this chapter deal with the practical elements of carrying out the research. The importance of triangulated data is discussed in the chosen research paradigm and the types of data collected to provide this and how the data is to be collected are discussed in the data Collection section.

The approach to the analysis of the different types of data is addressed in the next section. This section addresses the unit of analysis chosen and the implications of this choice for the study as well as the ways in which the large amounts of data collected are reduced to manageable levels and then presented.

Finally the chapter considers the processes in the study that will be undertaken to ensure the validity of the research overall. This critical appraisal considers the internal validity of the research based upon a sound construction of the research paradigm, the validity of constructs within the case study and looks at the extent to which the study can be considered valid for wider use. The section is completed by an appraisal of the reliability of the research.

The case study of the emergence of Offshore Wind Power is set out in Chapter 4: Analysis and Findings. The chapter is structured, in part, to provide a case study for future researchers. First a description of the industry is provided that helps define its structure and constituent organisations. Following this the story of offshore wind power is set out from 3 perspectives;

- A timeline of its development from start-up (pre-2000) to 2018
- A systems review of the activities making up the industry as a whole
- Observations of the industry via the annual supply chain conference and interviews held with participants.

The analysis of the case from the three perspectives provides a basis for a number of conclusions about the case and these are set out in the final section of the chapter. The conclusions look at;

- Has offshore wind power emerged as an industry?
- Is offshore wind power viable?
- What actions in this case contributed to emergence and viability?

Chapter 4 concludes with a brief review of how the case addresses the research questions set out in Chapter 3.

The discussion chapter (Chapter 5) considers the findings from the case in the wider context and aims to identify the generalisability of insights from the case, in particular to identify findings which confirm existing knowledge, those which extend this knowledge and any elements which are new findings.

The chapter starts with a review of what the existing literature reviewed in chapter 2 has to say about the case of offshore wind power. This critical review looks for any contradictions between the stated theory and the particular case as well as any confirmation of the theories provided. It then goes on to consider how systems approaches can be applied to the case in order to support the aims of industry emergence and viability.

The chapter follows this by critically reviewing whether ‘industry as a system’ is a helpful basis for defining industry during its emergence. A number of particular benefits for this formulation of industry are discussed.

The discussion chapter concludes with the proposal that a framework may be constructed that supports the emergence of viable industries.

Chapter 6 sets out a framework that meets the parameters suggested from the case of offshore wind power and addresses the second research question of how to interact with an industry to support emergence in a viable form.

With the framework stated, the chapter then explains how early tests of the validity of the framework can be undertaken without access to a new potential industry. This is demonstrated via the application of the framework to the recent case of wave energy as an initial validation. The findings from applying the framework to the external case are then discussed.

The chapter concludes with a discussion of the validity of the framework.

The conclusion chapter of this thesis (Chapter 7) begins by revisiting the original research aims and objectives and discusses what the research has been able to conclude with respect to these.

The quality of the research is critically assessed in the light of the research paradigm and justification is made for the validity of the research claims. The research is then set in context by consideration of its significance and novelty and this leads to a stating of the contribution to knowledge that the research represents.

The chapter closes with three sections that consider the individuals and groups who may benefit from the contribution to knowledge that the research represents; what limitations exist within this contribution and what further research is appropriate to build upon the defined contribution to knowledge.

2. Literature Review

2.1 Introduction

Chapter 1 sets out the desirability of being able to promote the emergence of a new industry. This chapter seeks to address the question of the extent to which the existing literature provides knowledge on how this might be achieved.

The research is carried out in 'Mode 2' as described by Gibbons (1994). Gibbon's thesis is that traditional forms of knowledge production, rooted in the context of a single discipline (Mode 1) are supplemented by a form of knowledge production that is trans-disciplinary and fits within broad social and economic contexts (Mode 2). This 'mode' highlights the need to consider a broad sweep of literature to fully address the economic and social aspects of the research questions.

In the initial stages this literature review examines the underpinning theories that relate to the phenomenon of 'industry emergence'. To do this the review followed a methodology informed by systematic review that highlighted two broad different strands of literature looking at the phenomenon of emerging industry;

- Economics
- Business management

Economic papers come from the evolutionary economic tradition originating with Schumpeter and developed into Industry Life Cycle models by Nelson and Winter (e.g. Nelson and Winter, 1982). The evolutionary view is important as it discounts the idea of static, equilibrium economics of the Marshallian norm and investigates dynamic economic forms. The economics strand also covers aspects of 'cluster theory' (the competitive benefit of related firms being spatially close) which evolved into economic geography and evolutionary economic geography. A final strand of the economics understanding building from economic geography is that of industrial ecosystems – initially where co-located firms in different industries benefit from shared material and power interchange and extended to understand the interaction of heterogeneous firms not-necessarily closely located.

The business management literature is more disparate but covers the areas of strategy; industry forms; entrepreneurial activity; innovation; organisational learning. The principle area impacting this research is the strategic stance (levels of collaboration v. competition, internally focussed research or externally) firms take during industry emergence and the impact of different forms of industry (mass market or complex product systems). These areas lead into the others e.g. strategy and entrepreneurial intent; forms of innovation etc.

The collected literature has a second dimension of grouping relating to the ontological basis. Studies are either objective (exemplified by econometric studies) or subjective (exemplified by entrepreneurial intent studies – there are also objective business studies e.g. patent-counting innovation).

The review of the literature highlights the definition of industry and identification of the constituents of a particular industry as a non-trivial matter due to the difficulty in setting boundaries and defining membership of an industry. This is a particular issue for industries that have not fully emerged and the third stream of literature reviewed, Systems Thinking, contributes to this.

Systems Thinking and systems approaches are evident in more recent business and economics literature as will be shown. This is occasionally explicit, but more usually through use of systems terminology.

The early theoretic investigations of General Systems Theory are initially covered, but the focus turns to ‘Systems thinking’ approaches such as Ackoff’s f-laws and Senge’s archetypes which have the specific intent to be applicable in real world situations. Consideration of the ‘viability’ element of the seed question leads to the work of Miller and Living Systems Theory and Beer’s Viable Systems Model.

With these theory underpinnings investigated a review of case literature relating to industry emergence is then carried out. The case literature makes frequent reference to the difficulty of contemporary study and the need to do more research in this area. The studies themselves are based on post-hoc analysis and follow the pattern of looking at particular aspects of theory as it relates to industry emergence, rather than of industry emergence as a whole.

A published review of the case literature shows that research is built upon understanding mass-market / product based industries and does not address infrastructure / capital equipment / CoPS type industry. The need for a grounded approach is apparent and expressed and informs this study’s research design.

Overall the literature provides investigations and explanations of particular aspects of industry emergence without giving an over-arching understanding.

A simplified view of industry emergence can be constructed that suggests industries spontaneously emerge via entrepreneurial action as the result of a technical or market discontinuity (disruptive innovation or de-regulation). The success rate of such industry emergence is considered to be low although no studies provide quantitative data on this. The studies highlight a number of contingent factors that impact on the emergence and may help or hinder the emergence. It is noted that this view is constructed from the consideration of mass production product only.

The existing literature is helpful if trying to decide:

- When did the industry reach emergence (via indicators such as dominant design, firm shake out, changing innovation stance)?
- What should the firm do to benefit from the new industry (collaboration, first mover advantage, innovation styles)?
- Is the firm in a good place to benefit (antecedent industry, supportive technology institutions etc.)?
- Is policy helpful to the emergence of industry (yes – improve legitimacy, reduce risk; no – empty categories, lack of consensus within industry)?

However none of existing literature directly answers the question '*how do we create a new viable industry'*, and for each of the helpful features there are counter examples. The summary shows that there is a research need to observe an industry during its emergence stage using a grounded approach that builds understanding of industry emergence as a whole.

2.2 Literature Review Methodology

The literature review has been undertaken to establish a business-centric view of actionable approaches to early life cycle industry sectors within the context of UK offshore wind power generation. As a consequence the review addresses the research question from two perspectives – from the view of an industry as a whole, and from the perspective of individual firms.

The review has been informed by the systematic review considerations put forward by Tranfield et al (2003) and also by more traditional literature review practices, such as following paper citations and developing constructs, and the previous knowledge and experience of the author.

Systematic Reviews are characterised by the explicit setting of inclusion criteria prior to starting the review. The author was concerned that this review should leave space for themes to emerge during the review hence the need to adopt elements from more traditional approached to literature review. While the resulting protocol does not strictly follow the systematic literature review approach, the author believes it to be fit for purpose. The following paragraphs attempt to provide more detail on the protocol.

The thematic area implied by the research question;

"How do we create a sustaining industrial system for Offshore Wind Power?"

… is very broad. There is a clear need for an initial scoping study to help surface appropriate search terms and clarify boundaries to the literature review. This was carried out via an initial search of databases (as shown in Table 2.1 below) for the terms "industry emergence" AND "case".

Table 2.1: Scoping study search results

	Emerald	ABI Inform	Web of Science
"industry emergence" AND "case"	28 results 11 selected for review	65,982 results (279 in abstract only) 8 selected for review	14 Results 8 selected for review

Following the collection of these papers a further reduction was carried through removing duplicates and initial reading of abstracts. This led to final group of 27 papers which focus on research of the phenomenon of industry emergence, or phenomena related directly to aspects of industry emergence. Selected papers that develop theory were included in the review where they; 1) focussed on industry life-cycle, and 2) examined research issues.

Following this work, the scoping was extended to cover respected peer review journals such as Industrial and Corporate Change and the International Journal for Management Reviews which were considered as likely to contain relevant papers.

Back issues of the journals were searched for articles that related to change or development of industries as a whole or articles that related to the change or development of individual firms. No selection or exclusion was made based on theoretical background to the papers or on the type of papers e.g. empirical, conceptual, review papers at this stage.

This scoping study surfaced key search terms and consistent theoretical constructs.

Table 2.2: Search terms and theoretical constructs

Search Terms	Theoretical Constructs
Industry / Industrial Evolution Industrial System Supply Chain	Industry Life Cycle Evolutionary Economics Systems of Innovation Complex Products and Services (CoPS) industry Resource Based View of the firm Organisational learning

These terms were then used to conduct a systematic search of relevant bibliographic databases including; ABI/ Inform, Emerald, Web of Knowledge

Table 2.3: Search term results by bibliographic database

Search term	**Emerald**	**ABI / Inform**	**Web of Knowledge**
"Industry Evolution"	141 journal articles (all fields) 10 in abstract or title	2088 articles (peer reviewed) 284 in abstract or title	218 in topic 164 when refined for social science domain, business economics / social sciences other topics / OR management science topic
"Industrial Evolution"	41 journal articles (all fields) 4/5 relevant 1 in abstract or title (not relevant)	730 articles (peer reviewed) 121 in abstract or title	129 in topic 64 when refined for social science domain, business economics / social sciences other topics / OR management science topic
"Industrial System"	603 journal articles (all fields) 16 in abstract or title (2 relevant)	1289 all 108 in abstract or title	697 in topic 122 when refined for social science domain, business economics / social sciences other
"Industry system"	35 journal articles (all fields – 1 relevant) 1 in abstract or title (not relevant)	139 all 18 in abstract	120 in topic 38 when refined for social science domain, business economics / social sciences other topics / OR management science

The selection of relevant papers from those highlighted in the search occurred by focusing on those where the key terms were in the title or the abstract. Within this group exclusion criteria were developed e.g. where the ‘industry system’ referred to is a piece of technology; or where the industry evolution described is anecdotal rather than grounded in some tangible evidence – changing print technology described as an evolution of the print industry when its described effect is solely a change of market offering for a single firm.

The review surfaced the need for a body of literature that could bridge the gap between individual firms, groups working in concert (supply chains) and whole industries. Regular use of terms such as “complexity”, “dynamics” and of course “systems” suggested to the author that writings in Systems Thinking might provide this perspective. These terms were used to search the databases named above and the papers identified were sifted based on their match with the previous criteria i.e. relating whole industries development, development of individual firms or supply chains and not concerned with single technology issues.

The protocol followed does have some limitations. While the initial scoping study is relatively unconstrained there is always the potential that important areas are missed. There is therefore an iterative element to the database search stage to allow the extension of the search if other important topics surface during the literature review. Similarly, inclusion and exclusion criteria were developed and refined as the review progressed. As a result some previously excluded papers were re-considered while others became less important.

The final cohort of papers was evaluated to draw out the consistent themes and to assess the level of actionable insight these themes could provide to the Actors within the Offshore Wind Power market. This is discussed further in Chapter 3.

The final element of this literature review was to return to the case literature as the data analysis stage commenced to ensure the analysis and discussion addresses any new knowledge developed during the research. The literature is similarly revisited in the discussion of findings (chapter 6) where this research is suggesting new knowledge.

2.3 Underpinning theory – Economic literature

This section will provide a broad over view of the literature that relates to;

- Industry
- Evolution of industries
- Industry life cycle
- Cluster / economic geography

- Institutional impact on industry

The literature comes from the Schumpeterian tradition of evolutionary economics rather than neoclassical Marshallian economics and the review will show why this must be.

To begin the inquiry, the researcher must have an underpinning concept of what an industry is.

2.3.1 Industry

The Oxford English Dictionary describes industry as:

> "*economic activity concerned with the processing of raw materials and manufacture of goods in factories*" - as a verb and:
>
> *"a particular form or branch of economic or commercial activity"* - as a noun.

In the United Kingdom industries are identified by their SIC (Standard Industry Classification) codes. These are self-reported by organisations who identify themselves to be operating within one or more industries as described in UK SIC 2007 (http://www.ons.gov.uk) maintained by the Office for National Statistics (ONS). Similar classifications exist in other territories, maintained by other bodies – in the USA this is also known as SIC, in Europe the codes are NACE and for the United Nations ISIS.

These codes are used for the development of econometric statistics and have proved useful within this purpose for many years, however the self-reporting of industry logically leads to in-accuracies. If the firm is a producer of electronics for automotive use, is the firm in the electronics industry, or automotive industry, or both? If an industry sector does not have a specific SIC code is it not a separate entity? It is also natural that the classification codes lag behind industry development. The UK's SIC was established in 1948 and has been revised in 1958, 1968, 1980, 1992, 1997, 2003 and most recently 2007 as industries converge, spin-off or disappear.

Other tangible evidence of an industry comes from the existence of a trade body or association. Examples in the UK include the Society of Motor Manufacturers and Traders (SMMT) for the automotive industry and Oil & Gas UK (aka UK offshore operators association) for the offshore oil industry. Membership of such organisations is optional and there may be more than one organisation representing a given industry. Nonetheless the existence and activity levels of such bodies is an indication that a group of companies believe there to be an unique industry sector to be represented.

This shows that the objective definition of what is an industry is a non-trivial problem. Nightingale (1978) sets out the problem of Industry definition, and its separation from a market definition as follows:

> *"Contemporary microeconomic theory assigns an unambiguous meaning to 'industry' only in the cases of perfect competition and perfect monopoly. Outside these theoretical extremes there is no theoretical concept to which the term 'industry' can usefully be applied."*
>
> *"The term 'market' is in a not much better situation, with the logic of the theory forcing each product of each producer outside of perfect competition to be assigned its own 'market'."*

Nightingale notes that some progress is made towards an analytic definition of an industry by Andrews (cited in Nightingale, 1978) i.e. '*an industry is defined as any grouping of individual businesses which is relevant when studying the behaviour of any one such business*'. To make this a more practical proposition, Andrews also defined a chief characteristic of such groupings as firms that operated sufficiently similar processes and techniques. Nightingale concludes that membership of an industry depends on the planning horizon being considered and that each investigation will require its own frame of analysis.

More recent work by McGee, Thomas and Pruett (1995) identifies the inadequacy of SIC code definition:

> *"Industry and market boundaries are porous and 'fuzzy' especially where globalization is taking place."*

In Srai et al (2017) the authors noted this blurring of boundaries as an ongoing effect. McGee et al (1995) suggest that the solution is to make justification of the sample frame an explicit part of any study design.

When attention turns to industry life-cycle analysis McGahan observes that industry boundaries are not easy to spot especially during the fragmentation / emergence stage (McGahan, 2004).

It must be concluded then that industry definition is not a 'solved problem' and this research seeks to address that challenge.

2.3.2 Industry life cycle

If the definition of an industry is not as clear as might reasonably be expected then the conception that an industry might arise, progress, sustain and disappear is more straight forward. As McGahan

(2004) states, the idea is *'so embedded it's taken for granted and forms basis of strategic investment decisions'*

The notion of an industry life cycle derives from the earlier concept of a product life cycle (see Foss 1996 for a summary).

The phases are described in a variety of near interchangeable terms covering four distinct phases:

- Emergence (introduction, fragmentation)
- Growth (shake-out)
- Maturity
- Decline

The linkage between product and industry life-cycles is natural as many industries emerge from a single new product, or at least new product technology, but this need not necessarily be so. The car industry started from the first car – there are now many distinct elements to this industry but they can all be traced back to this 'genesis'. The electronics industry grew from the transistor – boosted with the development of integrated chips. The personal computing industry started from the first PC. Other modes of emergence are however possible. An alternative scenario is presented in the example of the electronics gaming industry (see Izushi & Aoyama, 2006). The authors show how this industry has multiple start points (arcade machines in the USA, animation in Japan and PC coding in the UK) and yet has converged towards a single industry.

If there is a recognisable and regular pattern of progression for an industry, it is reasonable to look for the forces that direct this. The next section describes the current understanding on how industries progress through the broad life cycle described above.

2.3.3 Industry evolution

As Pindyck and Rubinfeld (2013) state;

> *"Microeconomics deals with the behavior of individual economic units ... consumers, workers, investors, owners of land, business firms ... explains how and why these units make economic decisions."*

The discipline must therefore provide some understanding and explanation of the behaviour of an emerging industry.

There are competing schools of economics – a mainstream 'orthodox' approach building on the work of Alfred Marshall which, as Nelson and Winter (1982) describe, is built upon the 'structural pillars' of maximising behaviour in firms and equilibrium. This is contrasted by the non-equilibrium school which builds upon Nelson and Winter's Evolutionary Theory of Economic Change (see Nelson and Winter 1982).

Neoclassical economics is the dominant discourse in economics but the approach takes a number of simplifying assumptions of homogeneous firms, equilibrium conditions and maximising behaviour in firms to develop its models and insights. These may be sensible simplifications looking at firm behaviour across mature industries but they are inappropriate assumptions during the early stage of an industry where by definition the status is in disequilibrium and firms take different forms.

Evolutionary economics (Nelson & Winter 1982, building on the works of Schumpeter e.g. creative destruction in Schumpeter, 1942) takes as its environment heterogeneous firms, stochastic entry and non-equilibrium conditions. This is clearly a more accurate description of the state of an emerging industry. The broad manifesto of evolutionary economics can be read in Boulding (1991) and a defence of using generalised evolutionary theory in economics in Aldritch et al (2008).

This area of evolutionary economic theory is tested and developed via models (e.g. Batten, 1982; Winter, 1984) and a number of common elements (regularities) are brought forward:

- the role of innovation driven by or related to new entrants to industry
- the need for analysis of heterogeneous firms (differing sizes and capabilities) and (random) stochastic entry of new firms
- the influence of wider economy and 'local' socio-economic factors
- the lasting impact of prior decisions (path dependency)

It is this evolutionary economics school that offers most support for investigations into the progressions of industries through their life-cycle. However, while these model-based papers help build an understanding of the evolutionary behaviour of industries in general, they do not look at the case of specific industry. This is addressed further in the review of case-based literature later.

2.3.4 Clusters (Economic Geography)

The evolutionary economics models of industry evolution suggest factors that can be seen in emerging industry without consideration of how wider factors might impact on the behaviour of firms (including emergence) such as the proximity of firms.

Prof Michael Porter introduces the notion of 'clusters' in his highly influential book *The Competitive Advantage of Nations* (Porter, 2008). Clusters are a geographic agglomeration of firms which Porter claims have the impact of:

- increasing the productivity of firms in the cluster
- driving innovation within the firms, and
- stimulating new businesses in the cluster

Further, it is proposed that at some scale a threshold is reached where the geographic concentration achieves a sustained position of competitive advantage (critical mass). Silicon Valley is cited as an example.

This idea drives many political agendas. Scotland's then First Minister, Alex Salmond, quoted the beneficial role of having '*the place decisions are made*' within the economy in his speech to the Offshore Wind Power Conference in 2011. Scotland's development agency, Scottish Enterprise, has had an explicit policy of developing clusters in selected industries (including Offshore Renewable Energy).

The importance of clusters is investigated within the discipline of economics e.g. Cumbers (2003, 2007). Such studies find the frequently argued benefits of co-location are questionable. In Cumbers (2003) it is argued that it is the networks of connections (which may be local or may be international) that is more important than the local mix.

The definition of an industry discussed above also touches on the importance of firms' impact on each other and so clusters (or at least geographic agglomerations of firms) may have a role in defining industry boundaries.

A final element to the general topic of cluster is the interaction of firms and institutions (especially educational institutions) that are described as making up systems of innovation - see Cooke (2001). Interaction can be positive or negative. Cooke's work suggests that Europe's innovation gap with the United States can be best explained by excess reliance on public intervention, signifying major market failure.

Feldmann investigates the development of an entrepreneurial cluster in the US (Feldmann 2001) and identifies that the (business) conditions literature associates with entrepreneurship in fact lag the establishment of this activity rather than lead it. Implying that it is entrepreneurship first, rather than condition setting, that is important.

The key factors identified in this paper for the successful formation of a regional industrial cluster are;

- Supportive social capital
- Venture capital
- Entrepreneurial support services
- Actively engaging universities

Porter returned to clusters in 2000 to consider the relevance of local clusters in a global economy (Porter 2000). The author recognises that many of the original rationales for location benefits have been eroded by developments in technology and the opening of markets (as identified in Cumber 2003) but argues that clusters (as geographic concentrations of interconnected companies) remain a feature of economies at all scales (local, regional, national). The suggestion is that despite the original reasons being diminished in importance with globalization, new influences of clusters on competition have taken on growing importance in an increasingly complex, knowledge-based, and dynamic economy.

In this idea of the importance of inter-connections in firms for competitive advantage, Porter previews the systems based development of clusters into economic geography. This will be explored further in the ‘systems’ section looking at Industrial Ecosystems.

2.3.5 Institutional Impacts

'Institution' is a term given used within economics to describe “*systems of established and embedded social rules that structure social interactions.*” (Hodgson, 1988). As with the term 'industry' there are on-going definitional difficulties regarding the term. In the context of this enquiry the key aspect is those institutions that impact on the emergence and growth of industries.

Papers such as Choi et al (2011), Cumbers et al (2007), Edwards et al (2004) and Wong (2005) all consider that the 'institutional impacts' and the institutions being described are tangible organisations such as government agencies, educational establishments, trade bodies, venture capital firms.

Choi et al's (2011) review of the emerging hydrogen power sector in Korea identifies the institutional role of government, universities and public research organisations in developing a precursor stage for industry emergence. Edwards et al (2004) similarly identified the government and education organisations along with research institutions (organisations), financiers and trade bodies as key institutions that support industry evolution in his work on value creation.

In contrast Wong (2005) explicitly describes institutions as "*formal and informal rules, such as laws, regulations, market and organizational norms that actors generally follow*". This definition closely follows Hodgson (1988). Wong's analysis works to maintain this separation from the organisations that develop and apply these 'laws, regulations, market and organisational norms'. Nonetheless the same mix of tangible organisations (government bodies, trade bodies, research institutions) is closely identified with the laws, regulations and organisational norms. Of further relevance to this research, Wong shows how neither of the polar opposite policies in 2 territories (deregulation in the UK, regulation in Germany) helped the emergence of (onshore) wind power but more subtle 'obliging' policy support eventually led to positive outcomes. This complex response to policy is discussed further in section 2.6.4.

2.3.6 Summary

This section underpinning theories shows evolutionary economics as a broad field that has developed a range of themes and related theories that are directly relevant to the investigation of an emerging industry. These approaches work through the consideration of aggregate bodies of firms which operate either in similar (homogeneous) ways or in a random spread (stochastic) of different (heterogeneous) ways.

As such they have a strong explanatory power when considering the past behaviour of an industry, but do not provide insights into the behaviours of the individual firms that will make up a emerging industry, nor do the theories address the idea of long term viability of an emerged industry.

For this the review turns to literature that is related to business management.

2.4 Underpinning theory – Business Management Literature

As noted above, this section on underpinning theory for the emergence and viability of new industries considers literature from the standpoint of business management.

The review covers the following broad topics:

- Strategy
- Supply Chain Development

- Organisational Change
- Complex Product Systems

To begin with the review looks at the ways firms explore and create new opportunity through strategy.

2.4.1 Strategy

The section above on an economics understanding of industry life cycle identifies that the model of industry development over time is closely related to the concept of a product life cycle. This was first explored by Utterbeck and Abernethy in their work ‘Dynamic Model of Process and Product Innovation’ (Utterbeck & Abernathy 1975). This work links the strategic management of innovation in a business to the life cycle stage of a product. By implication, such strategic management approaches also vary within an industry life-sycle (described as ‘segment’ in their paper).

The authors consider the interlocking roles of product and process innovation. In particular they differentiate between types of innovation in 2 dimensions:

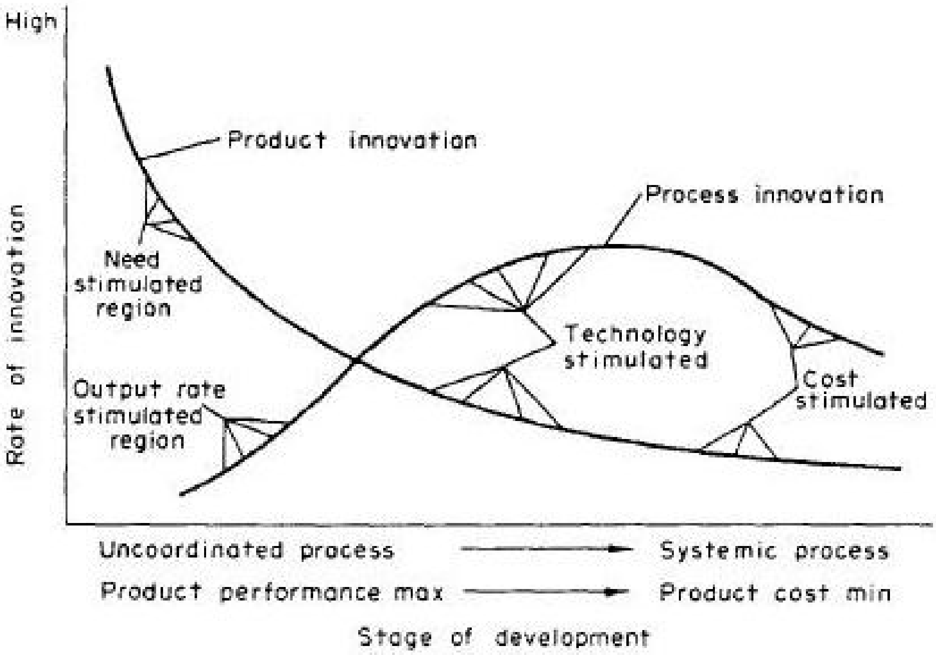
- Product / Process
- Original / Adopted

This differentiation is highly relevant to industry emergence as the authors ascribe a pattern of declining levels of product innovation through the development of an industry, with an arc of increasing then decreasing levels of process innovation. The nature of innovation is also seen to change from early 'original' innovation where technologies are developed that are specific to the segment, to later 'adopted' innovation where technologies are brought in from other segments.

This work suggests some clear patterns of innovation will be observed in the emergence of a new industry.

The expected changing nature of innovation is illustrated in figure 2.1 shown below.

Figure 2.1: Changing nature of innovation in a product life cycle



(from Utterback and Abernathy 1957)

Barriers to innovation are not constant through the development stage. During the early ‘uncoordinated’ stage, barriers relate to the perceived relevance of a product innovation, and by the later ‘systemic’ stage barriers relate to the perceived disruptiveness of the innovation to highly complex and integrated product and process systems.

In a follow up article (Abernathy and Utterback 1978) the authors identify that the model may be helpful in predicting why some innovations fail at set stages of an industry due to the necessary conditions not being in place for a given level of development.

The requirement for specific strategic stances within businesses during industry emergence is further addressed by Harfield in “*Competition and cooperation in an emerging industry” (*Harfield 1999). This paper builds upon the observation in Porter's Competitive Strategy book (Porter 1980) that, in an emerging industry, firms face a dilemma of placing industry advocacy against competitive self-interest and often the self-interest wins to the detriment of the industry.

Harfield examined the case of the New Zealand wine industry and found that a far more complex interaction of cooperation and competition exists in emerging industries. The stances taken went far beyond common advocacy for the industry (“building legitimacy” as described by Aldritch & Fiol, 1994). The case argues that cooperation is necessary for industry survival. The paper also puts forward the view that when talking about an 'industry', there is an element of geography at play:

"Local industry *players realize that dominance leads to decline and exit, whereas large* ***foreign corporations*** *might not understand (or care about) either the economic or social dynamics required for industry survival." (Harfield 1999)*

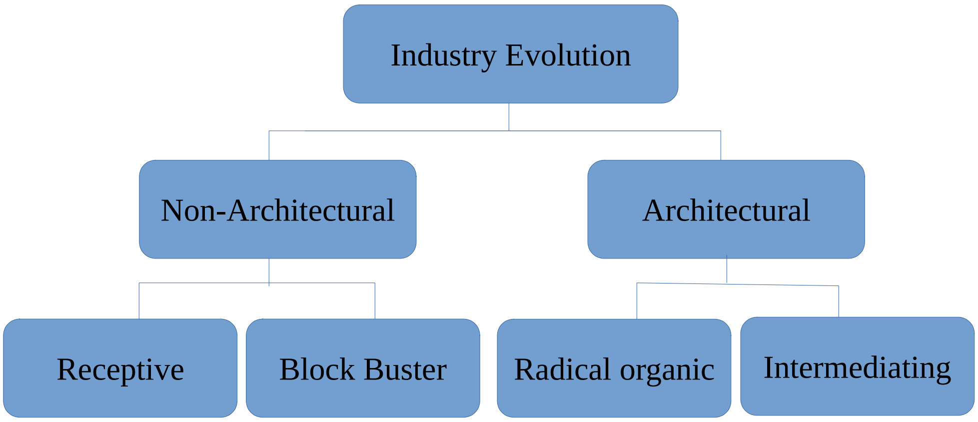
This idea that strategic imperatives may be different in emerging industries to those that are more mature is further supported by Aldritch and Fiol (1994). Aldritch and Fiol examined the institutional context of industry creation. They found that the pursuit of legitimacy was a driver of entrepreneurial activity that shaped both the industry and the institutional environment. This work has strong congruence with Abernathy and Utterback's work where the relevance of product innovation can be linked to the efforts made to legitimise an emerging industry.

The literature covered so far shows the benefit of introducing an understanding of current industry life-cycle stage into strategic decision-making. This can be taken further to argue that it is not solely an understanding of where in the life-cycle an industry is, but also to differentiate evolutionary paths that industry might take (McGahan 2000). The author argues that firms must understand how industries evolve if they are to align their investments with industry trends.

The work argues that the 5 forces model (Porter 1990) and industry life cycle model (discussed above) are not helpful to this understanding – the first due to its static nature and the second due to the difficulty in determining where in the cycle an industry is. If one considers the high firm entry rates marker of emergence highlighted by evolutionary economics models the limitation of the 5 forces model is clear – in the models terms it would signal a reduced attractiveness of the industry (more competition) whereas the life-cycle model would take this as the sign of whole industry growth and the impending stage of profitable growth.

McGahan provides a framework of 4 models of industry evolution to help firms understand the dynamic nature of different industries, and an evaluation process to help define which industry model the firm finds itself in.

Figure 2.2: McGahan models of Industry Evolution



The models are built on specific characteristics of industry structure, historic innovation path, investment opportunities and performance drivers. The contribution of McGahan's model to this research is that it underlines the need for an understanding of the 'dynamic' of an industry and shows how the 5 forces model (essentially a 'static' view) and the s-curve model ('dynamic' but without a fool-proof way of understanding at which stage the industry is) are inadequate.

While the work is helpful in overall terms for industry evolution, the need for an assessment of historical innovation paths and industry structure to limit the utility of the framework within an emergent industry. It also has little to say about the conscious effort to establish an industry long-term.

So far the discussion on theoretical understanding of drivers for firm strategy related to emerging industry has focussed the way firms address innovation, their competitive stance and how they might structure investment decision-making in an emergent industry. A firm must also consider whether or when to internationalise.

This is illustrated in the work by Løvdal and Neumann on the emergence of the marine energy sector (specifically wave and tidal sources) provides direct insight into the ways firms act strategically to secure their future within a technology defined industry (Løvdal & Neumann 2011).

This paper reviews the barriers to new innovations in marine renewable energy (specifically wave energy and tidal stream energy). It identifies that access to capital and support from political regimes were repeatedly identified by firms as the critical factors for successful industry establishment. The work showed that firms in this renewables sector used internationalisation as a strategy to address these factors very early in firm life – if the local market is insufficiently supportive, the firms will 'shop' internationally for the best geographic market to be in.

This is a critical insight as it highlights an internationalising route for emerging industries that national policies are not designed for. As an example national policies for support of (local) industry seen in the context of competition with other national interests may in fact provide support to extra-national firms.

This section shows that there are many different strategy drivers for firms in an emerging industry and while the literature is helpful in informing and explaining business-level actions within such an industry, it does not offer a collected view on how to promote industry emergence, nor how to ensure viability (or at least increase the longevity) of an industry.

Attention thus turns to consideration of the groups of companies that together provide the end-customer product or service in an industry – supply chains.

2.4.2 Supply Chain Development

If company strategy needs specific consideration for the case of operating in an emerging industry, then the same is true of the whole supply chain. As Mowat and Collins identify in their investigation of an emerging agriculture industry there is a need for '*disseminating reliable information about consumer behaviour'* to improve supply chain effectiveness (Mowat & Collins 2000).

The need to consider the whole supply chain is identified as important in the literature on innovation costs. As Bunduchi and Smart (2010) identify in their review of the literature on innovation costs in the supply chain, these costs impact on the adoption of innovations. Their work helps to organise the disparate elements of costs in a framework of six broad categories of innovation cost in three groupings:

1. development & 2. initiation

3. switching cost & 4. cost of capital

5. Implementation cost & 6. relational costs

This framework supports innovation in general, and innovation leading to industry emergence in particular, by highlighting a wider range of costs than might be initially identified. As the authors state:

> *“A strong rationale for investment ultimately increases the likelihood that the innovation will be successfully assimilated”*

Srai and Gregory (2008) address the need to consider whole ‘supply networks’ from a different perspective. The authors identify the need to analyse the relationship between between strategy and structure for entire Supply Networks. They develop a taxonomy of *Configuration Definitions* and a suite of tools for analysis and design which provide insights into the capabilities and performance of the whole supply network.

This work also provides archetypes of *Configuration* that;

> *“provides developing and emerging operations the critical order winning capabilities on key operational performance measures of cost, responsiveness and supply security to global market place demands and the effective management of risk.”*

(Srai & Gregory 2008).

This structure supports the development supply networks that are better able to perform in emerging industries. The development of a cross-supply chain strategic stance, and the configuration of supply networks to match this stance, improves the capabilities and performance of the whole network.

As well as the capabilities at an organisational unit level, the nature of the individual skills within the supply network (chain) will also have an impact on the trajectory of an emergent industry. This is exemplified by Izushi and Aoyama (2006) in their work investigating cross-sectoral skills transfer into the electronic games market. The work shows how three different progenitor industries produced games industries with distinct characteristics in three geographic locations. They argue that;

> “*the cross-sectoral transfer of skills occurs differently depending on national contexts, such as the social legitimacy and strength of pre-existing industries, the socio-economic status of entrepreneurs or pioneer firms in an emerging industry, and the sociocultural cohesiveness between the pre-existing and emerging industries*.”

This study nicely demonstrates the path dependency nature of evolved systems (explored in general in the economics literature) even where there is a degree of convergent evolution. It also ties into the open question of the importance of geographic proximity of actors in the emergence of an industry.

As with all the literature topics covered so far the theories and insights related to cohesive supply chain development have a place in the understanding of emerging industry, without yet providing a comprehensive approach.

2.4.3 Organisational Change

If emergent industries 'emerge' from other industries, how is it that organisations change, and what is the impact of this change in emerging industries? van de Ven and Poole (1995) propose a theoretical framework for organisational change that encompasses 4 idealised models of change:

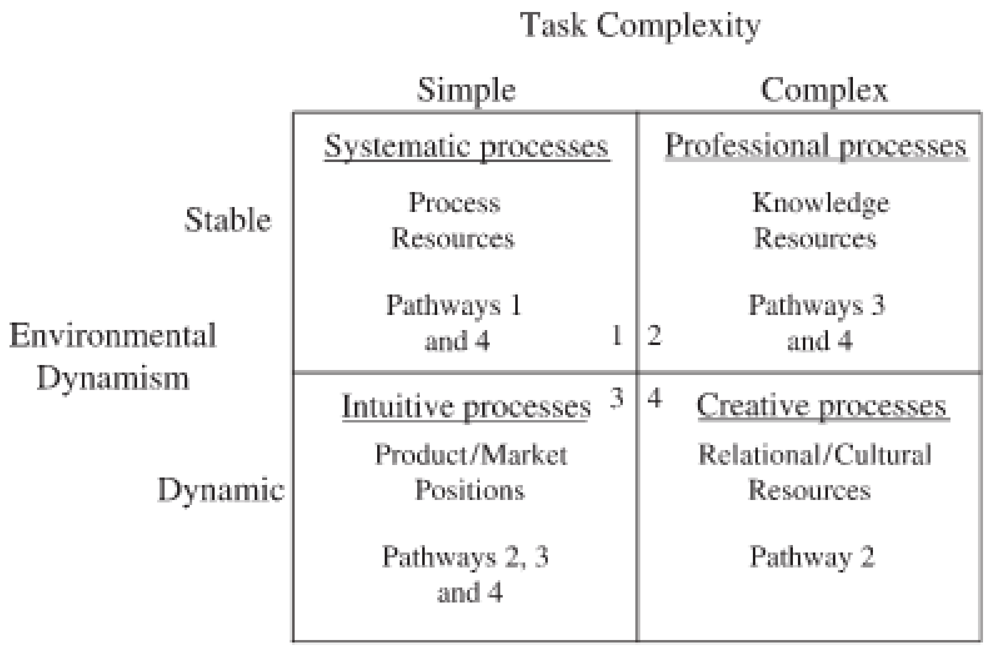
- Teleological (purpose-based change – e.g. to meet a desired goal)
- Life-cycle (change is inevitable and follows a consistent path)
- Dialectical (change is the result of contradictory forces within the organisation)
- Evolutionary (accumulation of small-scale adaptations that result in significant change over time)

The framework sets these four models on a 2 x 2 matrix with the dimensions of **mode of change** (prescribed – constructive) and **unit of change** (single entity – multiple entity). Actual models of change are then built up from combinations of these idealised models (described as motors for change). These combinations can be one 'motor' only, or a mix of 2, 3 or 4 motors. The 16 different models then allow for the great variety seen in case studies of organisational change. They argue that it is by considering the change from all four models that we best gain understanding of what is happening in any given case. This richness has relevance for the behaviour of firms involved in an emerging industry and all 4 idealised 'motors' can be conceived to operate in any given organisation. While this work may be of descriptive help and support understanding of historical cases, it does not provide prescriptive courses of action for specific industry life cycle cases.

This lack of prescriptive approaches is identified and partially addressed by Bowman and Collier (2006) in their work on the resource based view (RBV) of the firm as a strategy tool. They identify that there is a lack of operationalising of RBV to give guidance on how to apply the approach when developing company strategy. Their work investigates the resource *creation* process and identifies a need for a contingent approach taking account of the dimensions of Task Complexity and Environmental Stability.

This contingent approach is modelled in figure 2.3 below.

Figure 2.3: Contingent approaches for resource creation



(source Bowman & Collier 2006)

This work leads on from van de Ven and Poole (van de Ven and Poole 1995) in that it does set out contexts in which organisational change can be purposefully pursued to enhance strategic competitiveness (through development of VRIN resources) e.g. van De Ven and Poole identify that the best path for developing VRIN resources was where tasks were complex and the environment was stable (Knowledge Resources in Bowman and Collier).

In an emergent industry the environment is, by definition, dynamic. In this case Bowman and Collier postulate that pathways to create resources may include Luck (as the name suggests a fortunate combination of happen-stance leads to VRIN resources), Teleology (deliberate development of VRIN resources) and Alchemy (where the organisation is able to turn non-VRIN inputs into VRIN resources). 2 of the 3 pathways are purely descriptive (Luck, Alchemy) and the third fails to provide any specific direction for firms – however the approach does suggest that certain pathways are less likely to work in a dynamic environment. One could consider the advice to be to carry out careful recruitment to get the right individual or team that can get to the desired end goals without clear processes to follow.

If the resource based view does not entirely provide an agenda for directing and managing change in an organisation looking to thrive in an emergent industry, then perhaps an understanding of the ways in which firms go about identifying and implementing desirable change is helpful.

This brings the researcher to the concept of ‘ambidexterity’ – *‘the ability of an organization to perform dichotomous activities at the same time’* (Russo and Vurro 2010). This can apply to a number of aspects of firm activity;

- manufacturing stance (efficiency v. flexibility)
- strategic approach (differentiation v. lowest cost)
- innovation / organisational learning strategies

as discussed in Russo and Vurro 2010.

Of particular interest is the latter aspect of organisational learning strategies (and by extension, innovation).

In their paper on ‘Cross-boundary Ambidexterity’, Russo & Vurro seek to establish the parameters of intra- and inter-organisational learning from ‘exploration’ (internal investigations / R&D) or from exploitation (external collaboration / horizon scanning). Exploration and exploitation require very different learning cultures and the attempt to build both capabilities within a single organisation are costly and questionably effective. Russo and Vurro establish that (within the emerging and risky technology of fuel cells) a strategy of working with external collaborators for one learning style (e.g. exploration) while focusing on the opposite learning style (in this case exploitation) can provide the looked for improvement in innovation quality and performance. Clearly this finding has strong relevance for emerging industries in principle, and it can positioned as a general ‘rule’ for an emergent industry – foster both capabilities within the firm by collaborating with other players, while maintaining an ability to explore opportunities internally. This can be seen in the context of the ‘dominant design’ signal for industries leaving the emergent stage – i.e. develop ones own offering internally but be ready to exploit the dominant design ‘chosen’ by the marketplace.

So far this review has looked at the purpose-based drivers of organisational change where there is an end-goal or direction of travel that is being pursued by the firm. As van de Ven and Poole (1995) identify, change can be the effect of accumulated adaptations over time (idealised as Evolutionary change). This aspect of the nature of organisational change is investigated by St John et al (2003) to consider whether the product and industry life-cycle progression is as deterministic as studies (such as those described in the economics section above) suggest.

The authors provide a summary explanation of the drivers of industry life-cycle as follows:

> *“An initial period of market and technological uncertainties encourages frequent product innovations and appropriately alterable manufacturing capabilities but is followed by the*

emergence of a dominant design. With the dominant design, market and technological uncertainties decline, market demand increases, product characteristics become more homogeneous, and process innovations and refinements create rigid, albeit efficient, production systems capable of low cost manufacture of standard products."

The authors observe that this idealised progression does not apply in all industries. Where there are low entry barriers or low switching costs and rapid technological change volatility remains a feature and no mature, stable state is reached. This leads the authors to consider the impact of managerial decision making in times of significant customer / product / process uncertainty (Sony's failure to recognise VHS as the standard for video taping is cited as an example).

It is argued that the dialectical and teleological change modes of van de Ven and Poole (1995) have more prominence in this situation, driving the competitive dynamics that construct the longer term change in a given organisation and hence in an industry life cycle. In such a situation the product-process life cycle is not as deterministic as suggested by models, and is in fact an emergent property of the whole situation.

This analysis shows how a reasonable (and testable) view that holds true for behaviour summed over large populations (e.g. multiple industries separated in time) can mask more complex behaviour in which the 'local, here and now' drivers are very different. This clearly has strong implications for any approach to supporting industry emergence in a viable form.

Loss of determinism while maintaining consistent underlying drivers is a feature of system complexity in mathematics. The inability to predict behaviour in complex systems is balanced by the proposal that unpredictable behaviour may be driven by factors that can be simply defined. Flocking behaviour in birds and fish has been shown to emerge from 3 simple rules (Reynolds 1987, quoted in Burnes 2005):

- Don't get too far away from your neighbours
- Fly at the same speed as your neighbours
- Move to the centre of the flock

This has led to the idea that complexity may be a useful concept to bring into management research. The extent to which is applied formally has been investigated by Burnes (2005). Burnes notes that there is a long tradition of bringing theories from natural sciences into management research, and that the need for better theories is increasing not decreasing (increasing rates of change, more global competition, failure rates of change projects are tangible drivers of this).

The opportunity perceived is that moving from *'imposing top down, transformational change'* towards a *'self-organizing approach necessary to keep complex systems operating at the edge of chaos'* will result in better business performance.

The author critiques the movement by pointing out that the transfer of theories and techniques from natural science to organisations should be based on thorough understanding of the theories and a sound conceptual basis for the transfer. He further argues that this foundation is lacking – there is no underpinning work on transferring mathematical theories to forms that can be applied to organisations, then modelling to demonstrate applicability. The author concludes that when the term is being applied to organisational change it is being used principally as a metaphor and that while the rationale for bringing complexity into organisational studies is strong, more is required to make it intellectually sound.

Given the difficulties with application of complexity theory to organisations, is there an alternative way to build upon the dialectical / teleological modes of change within the organisation – and by extension industries as a whole? In Cordes et al, 2010, the researchers investigate whether industry evolution can be understood in terms of evolving corporate culture. The authors show how a cooperative corporate culture is beneficial to firm performance in a rapidly changing (and innovative) market. This cooperation is seen to deteriorate rapidly after a certain firm size is reached (regardless of market state) – although no fixed indication of size of the firm is provided.

The research demonstrates that the firm gains maximum benefit from a cooperative culture when this critical size is reached at the same time as the industry as a whole reaches a mature and stable level. Further benefits for the firm are then gained from economies of scale, rather than from speed and effectiveness of innovation and cooperation becomes less of a success factor.

The ability of a firm to change what it is good at thus becomes a factor for the success of a firm in the long-term, i.e. as industry moves from one stage to another. This aspect of firm behaviour is examined through the construct of *Dynamic Capabilities* (see Teece et al 1997, Eisenhardt and Martin 2000 for canonical forms). This theoretical construct extends the resource based view of firm competitiveness to examine how these resources are developed within firms.

How the construct may support strategic management is reviewed and explored in Ambrosi & Bowman 2009. Their review highlights the role of dynamic capabilities in responding to rapidly changing external environment through changed capabilities in the firm – of particular relevance in an industry in its emergent stage. The authors also show the link between evolutionary models of economics, the resource based view of the firm and dynamic capabilities and conclude that *'that* *dynamic capabilities describe intentional efforts to change the firm's resource base'* although they stop short of claiming dynamic capabilities as the root of all (strategic) change.

The authors then investigate what it is that shapes the dynamic capabilities of a firm and considers the processes and external pressures that create them. The authors conclude that possessing and deploying dynamic capabilities within the firm does not automatically lead to performance improvement (or competitive advantage) for the firm, particularly where the rate of change in the environment is high and the costs of change also high.

In the context of an emerging industry, as described in the economics treatments above, the role of dynamic capabilities of firms is likely to be heavily impacted by the rate of firm entry – success may come to the firm with the right capabilities *at the time* rather than to the firm most quickly able to develop them.

2.4.4 Complex Product and Systems (CoPS) Industry

The literature reviewed so far has taken a generic view of industry (not withstanding the commentary on the difficulty of defining a particular industry) in which arbitrarily large numbers of firms compete through alternative product offerings based on similar or dissimilar technologies to gain custom from a similarly arbitrarily large number of customers. It is clear that not all industry is configured in this way.

Hobday (1998) develops the idea that industries can be distinguished by the nature of their products, at a more abstract level than the technology used. The author identifies 2 industry types; mass manufacture industries (which are familiar to consumers and include automobiles, brushes, computers etc. and which fit the generic description above) and CoPS (complex products and systems) industries where the final product is made up of a number interacting elements that may themselves be mass manufactured or the outcome of a CoPS industry which may have very different characteristics to the generic industry model underpinning the theory discussion so far.

Examples given of CoPS industries include power stations, defence capability and are most frequently associated with capital goods projects and infrastructure as explored in Acha et al (2004). CoPS industry configuration and dynamics is therefore directly relevant to the case being looked at in this research.

The CoPS distinction is shown to have implications for researchers looking at various aspects of firm and industry dynamics. In Hobday (1998), the author looks at the different dynamics of innovation in a CoPS environment compared to Mass Manufacture and finds differences in organisational forms in the seperate industries; the project and the project-based firm are natural forms of organisation in a CoPS industry; products (or product families) and process based firms are the norm for mass manufacture industry.

The outputs of CoPS firms tend to be produced intermittently in projects or small batches and tailored for individual users, rather than produced continuously through a managed life-cycle and be standard (or customised) for groups of customers. In such cases the author suggests that the chief unit of analysis for competition purposes is the multi-firm project rather than the individual firm. This clearly impacts the relevance of the business theories explored above, although it is not clear whether the theories apply in principle to the new unit of analysis, or whether qualitatively different constructs are required. The idea of supply networks competing – rather than single firms – is explored later in this chapter (see the section on Supply Chain Ecosystems).

The extent to which theories relating to mass manufacture industries may still be applied to CoPS industries can be investigated in cases where organisations move from one to the other. Magnusson et al (2005) investigate the case of business in a CoPS type industry moving to a more mass production domain. In this paper the authors investigate the impacts on organisations and their ability to adapt as they move from a bespoke engineering environment (large power generation turbines) to a more mass market offering (smaller scale turbines to be used in a more distributed generation model). The research is particularly relevant to the case of offshore wind power generation.

The authors discover that it is the step from an experimental research and development focus to commercial production that is particularly difficult for incumbent firms. Their explanation is that whereas manufacturing of large power plants requires systems integration capabilities, distributed generators are based on a 'plug-and-play' logic where meeting a defined specification is the prime focus.

Davis and Brady in their paper (Davis and Brady 2000) address the CoPS difference from a more theoretical view point, and consider whether the Chandler framework for organisational capabilities (Chandler 1990 cited in Davis and Brady 2000), developed in terms of mass manufacture / service industry, has relevance for CoPS organisations. The authors find that the model can be adapted by considering project capabilities to be an additional set of organisational capabilities (alongside strategic and functional). Organisations change from looking for scale efficiencies to looking for economies of repetition.

This work is supported by Nightingale in his paper on ‘Product - process - organisational relationship in complex product systems’ (Nightingale, 2000). Nightingale investigates one of the interactions between project capabilities and functional capabilities as they apply in aero-engine manufacture. He argues that complex capital goods have specific innovation management problems that are not found to the same extent in simple products.

The author finds that complex products have the potential for “redesign feedback loops” whereby small changes have disproportionate effects on the innovation process. Avoiding these costly redesign feedback loops depends on reducing uncertainty, normatively by constraining the product parameters. Firms that can flexibly and efficiently allocate resources within the project, reduce uncertainty and redesign should be able to develop projects at lower unit cost.

So CoPS industry requires a different focus for internal resources to a mass-manufacture industry. Is there a similar variation when considering external resources such as inter-organisation processes? Rutten et al (2009) investigate the implications of being a CoPS industry for inter-organisational cooperation and innovation. They take the construction industry as an example and work with the proposition that it is the role of system-integrators to set-up and coordinate inter-organisational innovation in a CoPS industry. They conduct a comprehensive literature review to examine this topic and find a number of success factors relevant to the construction case derived from literature that can be applied by the system integrators. The success factors are identified within Network set-up factors and Network coordination factors and relate to new product development; strategic networks and alliances; open innovation and construction innovation. As the authors themselves identify, there are a large number of success factors identified without being able to select a critical few – this is perhaps an inevitable limitation of combining reductionist research in a complex environment.

A more constructive output from the work is addressing how a system integrator may be identified in an industry (construction in this case) by looking for three characteristics;

- an organisation that bring together dispersed resources and integrates them into a coherent system
- contractual responsibility for the functioning of the system
- project-based production (one-offs or small batches)

This definition is sufficiently general to be applicable in non-construction domains and may be helpful in terms of the industry at the core of this research.

There is significant support in the literature reviewed above for the contention in Peltoniemi, 2011 (explored in the case literature section), that the emergence of complex product systems industries requires separate investigation from mass market, product-based industries.

2.5 Underpinning theory – Systems Thinking

The underpinning literature on industry life cycle and drivers for industry emergence discussed from the domains of economics and business management take a reductionist approach that looks to break a problem situation down into discernibly different individual elements and consider each in turn.

There is an alternative view of how interacting and complex situations should be approached that aims for an understanding of the situation as a whole. This is the realm of systems. The following sections provide a brief review of potentially supportive systems approaches.

2.5.1 Introduction to Systems Thinking

Systems Thinking is the name given to a class of approaches to understanding and resolving issues where it is the behaviour that arises from the interconnection of nodes that is more important than the behaviour of the nodes themselves and the practitioner attempts to take all aspects into account rather than focussing on one (adapted from Checkland 1999 pp5).

Systems Thinking has developed from General Systems Theory which sought to provide a comprehensive mathematical treatment of system type problems. The work of Ludwig van Bertalanffly (see von Bertalanffy 1969) is frequently cited as the source of this work, but it also builds upon Norbert Weiner's cybernetics (see Wiener 1948) and Kenneth Boulding (Boulding 1956). The aspiration was for a meta-theory of systems expressed mathematically.

Whilst the movement for a General Systems Theory has not yet achieved its vision, it has introduced the important idea that some situations need to be treated 'holistically' i.e. treating all the elements as one 'thing' in contrast to a reductionist approach which seeks to break 'things' into their minimum parts. Other aspects that come to system approaches from this early work are the idea of **hierarchy**, an increasing level of complexity of systems made up of other systems developed into a variety of taxonomies by writers such as Boulding and Ackoff; and **requisite variety** (see Ashby 1958), the law that states a system must have a level of variety that matches its environment's if it is to be able to respond to changes in that environment.

Boulding set out the principle that systems are made up of other (sub)systems and that these sub-systems build a hierarchy of increasing complexity. The stages of this hierarchy have been adapted over the years but Boulding's original was;

1. static structure (a bridge)
2. simple dynamic system (a clock)
3. control mechanism / cybernetic system (speed controller)
4. "open system" / self-maintaining structure
5. “plant” level
6. "animal" level
7. "human" level
8. social organization level
9. transcendental level

(Adapted from Boulding 1956 accessed at https://www.panarchy.org/boulding/systems.1956.html).

Ashby (1958) sets out a 'law of requisite variety' which identifies that for a system to be able to self-sustain it must have as many ways (variety) of reacting to its external environment as the external environment has different ways of impinging upon it. An example frequently used to illustrate this is the business function of sales – with millions of customers, requisite variety suggests the firm requires millions of possible responses (e.g. product offerings). As this is normally impossible (but technology keeps looking to extend what is possible) systems must find a way of reducing the variety impinging on the system (e.g. by considering market segments not individual customers) and amplify the responses (e.g. give sales people leeway in offering inducements).

The systems movement (and in particular Systems Thinking) has made a number of contributions to 'problem solving'. The diversity of the way in which it is developing can be understood by considering a few key authors and their works.

Russell Ackoff was an early exponent of using systems thinking to understand organisations and how they work. He developed a series of 'rules' to help understand organisations that built upon his understanding of the underlying organisation as a system. These were rather quixotically named Management f-Laws and the original 80 f-laws has been added to over time (see Ackoff 2008). An example is:

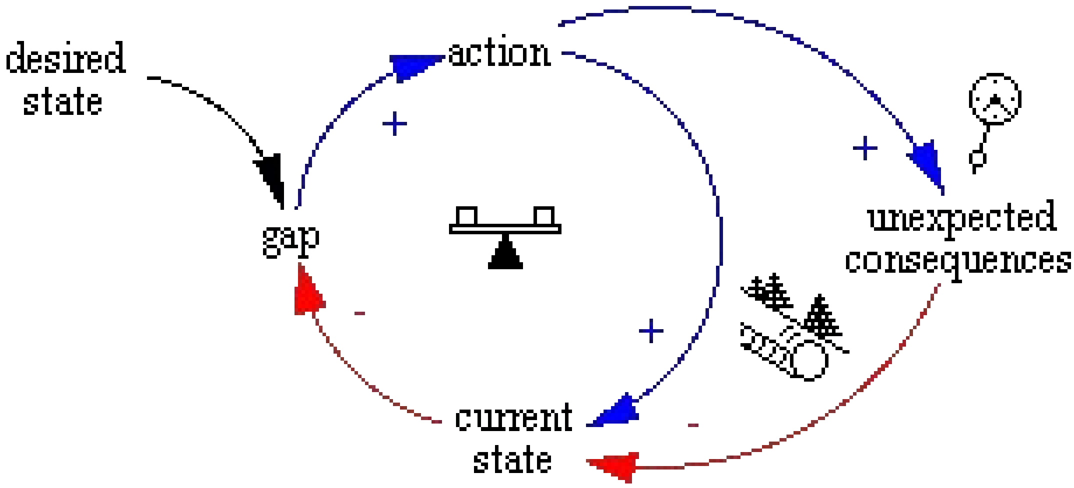
#81 "When nothing can make things worse, (literally) anything can make them better"

Systems Thinking does not imply a retreat from structured enquiry. In the late 60's early 70's Jay Forrester developed a modelling approach to whole systems that allowed insights into how particular parameters impacted on whole system behaviour (System Dynamics). Early success with his approach (outlined in his book 'Urban Dynamics' - Forrester, 1970) has led on to a large body of work by many practitioners. A example of the power of the approach is the World3 (Systems Dynamics) model behind the 'Limits to growth' book (Meadows et al, 1972) which showed how unconstrained consumerism would lead to eventual population crash. This Malthusian prediction was tempered by demonstrating how increasing rates of resource re-use and increasing technological development rates (within the model) could stave off this crash.

A key element of the approach is to build 'causal maps' of the interaction of system elements and then to consider the transformations that occur within the maps in terms of stock and flows. These can then be modelled numerically (by computer) and running the model with alternative scenarios imparts insight to the modeller that is independent of their inputs.

An approach to developing understanding of organisational systems that sits between Ackoff's laws and System Dynamics modelling comes from Peter Senge. The author outlines Systems Thinking as his 'fifth discipline' for managers in his book 'The Fifth Discipline' (Senge 1994) and contributes the idea of system archetypes to understand how (human-based) systems behave. These system archetypes can be illustrated through simple causal maps of the type used in developing system dynamics models, but without requiring the computational element. Some examples from the book are; fixes that fail, accidental adversaries, tragedy of the commons. Figure 2.4 shows a causal loop diagram for 'Fixes that fail'.

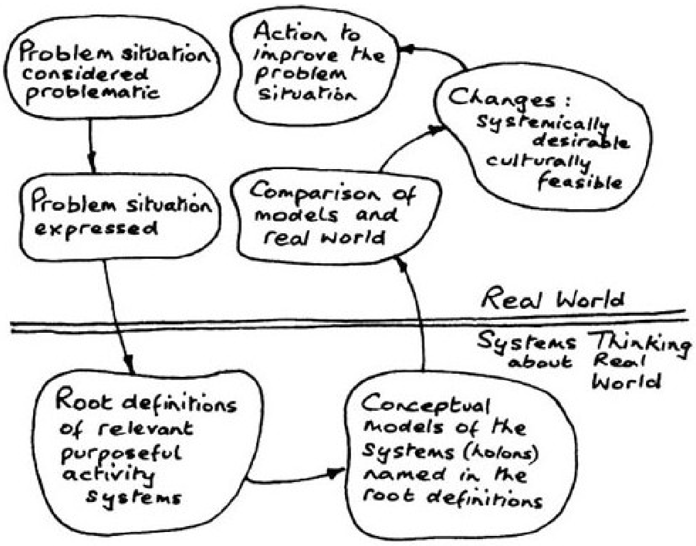
Figure 2.4: Fixes that fail – causal loop diagram (source http://www.systems-thinking.org/theWay/sff/ff.htm)



These archetypes provide both a diagnostic of situations and potential remedies for the reader.

Systems approaches are also developed for less clear situations. For such cases, Peter Checkland contributes Soft Systems Methodology (explained in Checkland 1999). This methodology is developed to help build a shared understanding amongst interested parties of a systems situation (he studiously avoids the term 'problem') and to consider a desirable outcome. This approach recommends using maps and models to describe the situation (such as the causal maps of Senge's system archetypes, or even Systems dynamics models) but does not stipulate that particular tools need to be used. The author does make suggestions of tools that may be helpful such as rich pictures, cognitive mapping and the like. Indeed the author suggests that even following the 7 stage process of SSM, shown in Figure 2.6 below (mode 1 use) is not strictly necessary when the practitioner is suitably experienced and the method is 'internalised' (mode 2 use).

Figure 2.5: 7 Stages of SSM (Checkland 1999)



The approach does contribute the formal idea of root definitions for the identified sub-systems and gives the CATWOE (Customers, Actors, Transformation, Worldview, Owners, Environment) mnemonic for this.

The systems approaches discussed above give an outline of how systems thinking differs from more reductionist and analytical approaches and while they may have utility in the situation being discussed (emergence of new industries) , the approaches are not immediately applicable to this e.g. who should be included in the 'interested parties' for an SSM approach, what elements should be included for a Systems Dynamics model, who would apply Senge's archetypes.

The following sections investigate some systems approaches that are more immediately applicable to this research.

2.5.2 Viable Systems Model

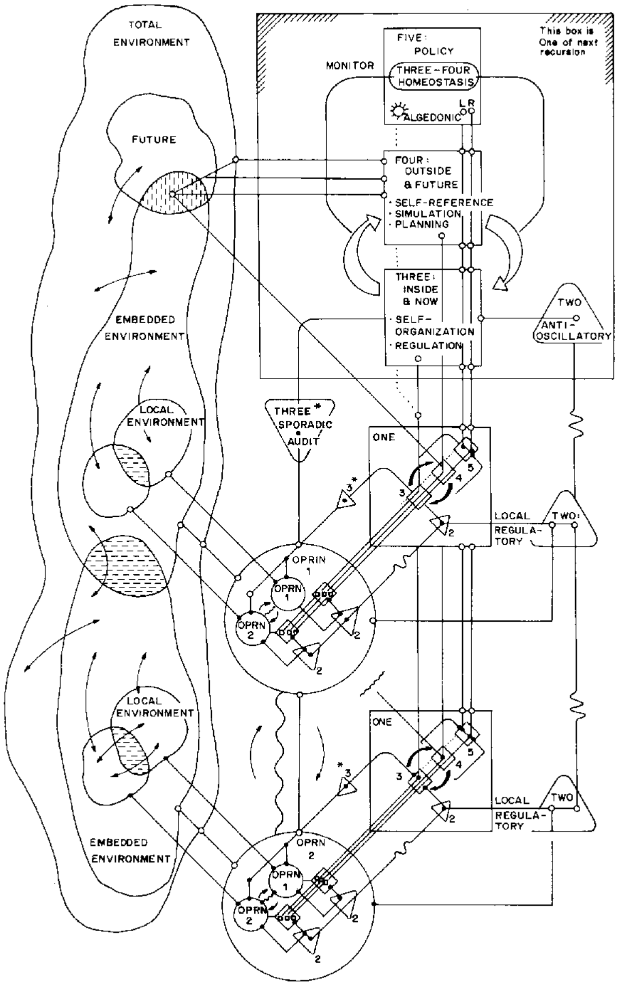
The Viable Systems Model was developed by Stafford Beer to address the problems of organisations and requisite variety (Beer, 1984) i.e. the ability of an organisation to maintain itself despite the change going on in its environment. He noted that in all cases the management of an operation has less variety than the operation itself, and that the operation in-turn has less variety than the market it seeks to serve. He suggests that to be viable an operation must reduce (attenuate) variety through processes of filtering and summarising and amplify (enhance) the responses possible to the system. In both approaches there are (changing) optimums e.g. too much filtering and summarising and important information may be missed, too little and the system becomes overwhelmed.

Beer argues that a viable system;

- is aware of itself
- maintains a distinct identity
- is able to repair itself

Beer summaries his ideas into a Viable Systems Model shown in Figure 2.6.

Figure 2.6: Viable Systems Model



Viable Systems Model sub-divides the system in focus (SIF being Beer's term) into 5 sub-systems, four of which are ascribed to management (systems 2,3,4 and 5.) as follows:

- System 5 is the boss. This system sets the direction, the policy and strategy of the system overall. It is reliant on appropriately attenuated signals from system 4 and provides readily amplified signals (policy and strategic direction)
- System 4 is the developmental (planning) system which concerns itself with the external environment and ideas of the future. Its focus is on improvement or necessary change to environment change. It is again dependant on attenuated signals – from system 3 and 3* to confirm how operation as usual is performing, and from its own survey of the external environment (e.g. horizon scanning).
- System 3 represents the tactical management of the system. It exists to step in where the system 1's (operations) are not performing as intended (e.g. unable to adjust to external

situations) and relies on attenuated signals to identify this. It provides ‘change’ signals to be amplified within the system 1s.

- System 3* is a subset of system 3 which bypasses system 2 and provides a direct audit channel between the system 1's and system 3.
- System 2 is the supervisory system which prioritises and co-ordinates the activities of operational units in real time. This may be as simple as an information channel between the systems 1s
- The system 1s are the operational units of the viable system. Unlike the previous systems, there are likely to be a significant number of these. They exhibit the recursive nature of the SIF in that they must in turn be viable systems and so have their own systems 2, 3*, 3, 4 and 5 acting within the constraints of the level above system.

Beer operationalised his model via a series of books ‘Brain of the Firm’ 1972, ‘Heart of the enterprise’1979, and ‘Diagnosing the System’ 1985. He was once tasked with using VSM to manage the entire economy of Chile – Project Cybersyn 1972-75. This experiment ended when a military coup took place. A recent paper by Espejo (2014) gives an overview of the endeavour.

Viable Systems Model in use

The viable systems model (VSM) has been used in support of research studies. The following papers illustrate the ways in which it has been applied.

Schwaninger (2006) provides a summary paper that documents a series of 5 cases where the VSM has been used in a diagnostic mode to help identify issues that need to be addressed for the good functioning of the system in focus. These cases cover;

- The structural transformation of a Swiss finance services company
- The redesign of strategy deployment (meta-system in the author’s words) in a media organisation in Brazil
- Improving cross-company cohesion in an multi-national chemicals firm
- Developing strategy in a health care organisation in Germany
- Examining the corporate ethos of a national petro-chemical company in Colombia

The author concludes that VSM is a powerful tool, capable of being applied in a wide variety of contexts. The author explicitly stops short of validating the underpinning claims for VSM theory (regarding viability it is assumed, although the author does not enumerate the claims).

Devine (2006) uses the VSM to gain insights into a National System of Innovation (NSI) – that of New Zealand in this study. His focus for the research is the way that considering the necessary variety within a NSI needed to match the variety in its changing external environment. The author considers that the more diffuse nature of a NSI over that of a firm requires the VSM to be translated to an ecological metaphor.

The work involves matching the principles of variety generation to the recognised tasks and drivers on a NSI. The work is largely theoretical and provides what the author describes as an integrating framework that helps understand the many elements of a NSI.

In particular the author states:

> *"The VSM approach, by focusing on purpose, and on the impact of the external variety on the system, provides a useful tool for assessing the effectiveness of policy options and how Government might intervene to enhance the operation of the system as a whole"*

The author shows that there can be a trade-off between variety and control for the system to maintain a fixed level of viability – i.e. to meet a changed environment the NSI could dictate (control) certain actions or increase variety (get more actors involved or reduce controls on existing actors).

The work recognises that in NSI the coordination is 'soft'; taking place through markets, through Government directions, and through relationships embodied in clusters, unions or industry groups, etc. rather than 'hard'; instructions that are expected to be complied with.

Governments generally can only manage such a system indirectly by facilitating the generation of the necessary variety, influencing strategic directions, filling gaps in the system and encouraging coordination.

Harwood (2009) uses VSM to consider the changing structural dynamics of the Scottish Tourism industry following the demise of the Area Tourist Board (ATB) in 2005. The ATB had the role of bridging between institutional policy makers and the private sector businesses that make up the tourism industry. The research starts from the observation that the engagement between policy makers and tourism companies had broken down – the replacement structure for the ATB, Area tourism partnerships (ATP) had been ineffective.

To carry out his research, Harwood makes use of documentary sources primarily, augmented by interviews with tourism practitioners. A particular focus is on the VSM principle of a systems ability to maintain its distinct identity.

The use of VSM as an analysis framework allows the author to identify a number of issues authority of ATP spokesperson, exclusion, Local Authority commitment, compliance, DMO (destination marketing organisation) proliferation, DMO definition, and control, prescription, legitimacy, involvement, centralisation-localisation and financial support.

The author proposes that the analysis (synthesis in Checkland's terms) reveals the structural integrity (or lack of) of the Scottish tourism industry at different levels. At the levels of the industry and locality there appears to be regulatory coherence, albeit marred by poor connectivity with the local level. At the local level, tourism groups exhibit viability and sustainability.

Dysfunction is apparent at the level of the Area. Industry representation on the ATP is through a spokesperson, but the authority to speak on behalf of the industry is questionable. This raises the issue of the ATP's engagement with practitioners at a local level.

The proposed solution, by participants, is the need for a membership-based group at this intermediary level – a return to the former structure. The author suggests that it was the imposition of a new structure 'top-down' that started the issue, and the lack of recognition of a system-reinforcing role for the ATBs that led to the problem developing.

Adham et al use the VSM in combination with theories related to innovation systems as the conceptual framework to describe and explain the functions and relational structure that exist among agencies and institutions within one policy implementation area in an emerging economy. The context is biotechnology industry development policy in Malaysia.

The research makes use of content analysis of official documentation (published data, ministers' speeches, technical reports) and interview transcripts to populate a VSM derived framework. The functions identified for the relevant agencies are the mapped onto the 5 VSM sub-systems.

The authors thus produce a model of a complex system that helps to explain the key functions and inter-relationships of the different agencies and provides insights that suggest possible improvements to the overall system. These recommendations relate to the lack of a system 2 function (real-time coordination). This outcome from the use of the VSM justifies the authors putting forward their methodological approach as of utility to future researchers when considering a systems approach in their research design.

In Shoushtari, 2013 VSM is employed alongside the Supply Chain Operations Reference model (SCOR) to support the redesign of a national scale supply chain network largely under government management. VSM and SCOR together are considered by the author for the functional aspects of the system, the social side being addressed via Checkland's Soft Systems Methodology.

The author outlines the history of the combination of systems methodologies to enhance their use and shows, in particular, the use of the VSM as a framework to construct a systems approach rather than a model to be rigidly applied.

The context of the participatory research is the chicken meat supply chain network in Iran which at the start of the study was largely managed by the government. The growth in demand has implications for available resources from government or the growth of the size of government. A desirable outcome is a redesign which reduces government involvement in the management of the supply chain network.

The author uses the SCOR model to construct a schema of the existing industry. This show an industry strongly interconnected with other parts of the economy (e.g. industrial machinery and equipment, pharmaceuticals). In this context the impact this situation has is that other economic sectors are under the supervision of other ministries. To address this complexity, the author turns to the VSM framework and the idea of recursion to set out boundaries for consideration in the redesign. Within the framework the author identifies a number of 'weak points' mostly related to insufficient variety in coordination and management sub-systems to deal with the variety of production units.

The outline solution presented is similar to the 'root cause' described by Harwood (see above Harwood 2009) where agglomeration of producers in informal networks is used to reduce variety. The paper does not include any indication whether the proposals are presented to, or challenged by, the industry, nor whether they were adopted in any way.

A final paper making operational use of VSM is by Hildbrand and Bodhanya (2013) where VSM is used as a tool to help understand the complexities of the sugarcane supply chain. This complexity arises from the interaction of multiple agents with different views and expectations and competing objectives. The complexity is at the root of hard and soft issues that compromise the efficiency of sugarcane production and supply (e.g. over-capitalisation / under-utilisation).

The authors propose that, in addition to detail works on specific aspects, the industry needs a holistic view to better understand the complexity. They then select VSM due to its history of success in a variety of industries (information systems, finance systems, nuclear industry are some of the examples cited by the authors).

The authors combine VSM with qualitative research methods (principally interviews with participants in the supply chain) to derive a VSM 'diagnosis' of the supply chain to arrive at actionable insights to the 'current' situation. The examples highlighted by the authors are;

- local mill management lacks autonomy
- necessary operational measurements cannot be realised
- coordination is deficient
- strategic vision and strategy generation at an area level is missing

The authors criticise the VSM tool for lacking ways to handle the issues it so successfully highlights. Their proposed solution is to use other, more participatory, methods to engage stakeholders in the design of changed systems. This approach is congruent with the modelling stage of Checkland's SSM.

2.5.3 Living Systems Theory

An alternative to Beer's VSM that also aims to explain systems that self-perpetuate is Living Systems Theory by Miller (first expounded in Miller 1978). Whereas Beer seeks to describe all continuing systems in terms of 5 generic subsystems, Miller sets out twenty subsystems and processes that the author proposes are necessary and sufficient for all living systems. These are put forward as input-throughput-output processes. These are arranged into the three groups as shown in the table below.

Table 2.4: Processes in a living system

Systems Input Stage	Systems Throughput Stage	Systems Output Stage
input transducer: brings information into the system **ingestor:** brings material-energy into the system	*A. information processes:* **internal transducer:** receives and converts information **channel and net:** distributes information **decoder:** prepares information for use **timer:** maintains the appropriate spatial/temporal relationships **associator:** maintain appropriate relationships between information sources **memory:** stores information for use **decider:** makes decisions about operations **encoder:** converts information to needed and usable form *B. material-energy processes:* **reproducer:** with information, carries on reproductive function **boundary:** with information, protects system from outside influences **distributor:** distributes material-energy for use **converter:** converts material-energy into suitable forms for use **producer:** synthesizes material-energy for use **m-e storage:** stores material-energy used by the system **motor:** handles mobility for the system **supporter:** provides physical support to the system	**output transducer:** handles information output of the system **extruder:** handles material-energy discharged by the system

As with the VSM, there are a number of studies where LST has been used by investigators in a research setting.

Living Systems Theory in use

In Merker (1985) the author seeks to operationalise LST to help achieve effective management in a business enterprise. The author outlines a seven-step procedure for LST application that, it is proposed, can be applied to any business organisation. The author's objective is to use LST as the basis of a general theory of business.

The seven steps are:

- Identifying the system – LST suggests a focus on the 'decider' as the start point for this

- Identifying the system purpose – while this may be gained from policy or strategy documents (or similar) it is suggested a wider understanding in terms of system hierarchy is also considered
- Identifying inputs and outputs – these should both be physical (matter – energy) and informational
- Identifying the nineteen subsystems (NB later revision to LST identified a twentieth sub-system, producer) – the author notes there will be a many-to-many correspondence between business functions and LST processes (i.e. one function will contribute to many processes, one process will be embedded in many functions) but stipulates that the whole must be understood in terms of the LST processes
- Identifying the sub-system inputs and outputs – as before with the added stipulation of 'conservation of matter-energy' all system inputs must flow through to system outputs (including waste)
- Quantifying the inputs and outputs – the setting of variables that relate to the inputs and outputs (examples include cost, volume, lag, distortion, rate)
- Managing the system – analysis of the information gained from the previous six steps and decision making based on that information. Decision making includes regulation of the organizational system and implementation of the organizational mechanisms. Key diagnostics are of the form that e.g. inputs should have a steady-state value and range. Where these are exceeded a 'pathological' situation exists and the system must adjust -how does this happen?

Such steps are familiar to practitioners of business diagnosis and change (e.g. through Business Process Re-engineering, in this author's own career). The use of LST adds a layer of complexity to such analysis (the need to align business functions and LST processes) but does offer a rigorous framework to underpin analysis and decision making. The author does not identify whether this approach has been trialled.

Tracy (1993) aims to provide a review of the application of LST to business management and organisational behaviour. The author makes much of the need to integrate otherwise disparate elements of management and organisational behaviour theory to gain deeper insights into the system in focus and proposes Miller's LST as an appropriate framework. Examples of such elements include perception, learning, motivation, communication and organisational power.

Tracy identifies an extensive list of organisational behaviour topics to which LST has been applied; perception, learning, attitudes, needs, motivation, goal setting, planning, decision-making, leadership, group cohesiveness, socialization, roles, communication networks, conflict and cooperation, stress, power and politics, authority, influence, control, organizational structure and design, specialization, environmental demands, culture and personality, growth and development. The sources of this work are cited as Merker 1985, Miller 1978, Miller & Miller 1991, Taormina 1991, Tracy 1989 & 1992, Weeks 1991 (cited in Tracy 1993).

Tracy then shows how LST can be applied to a number of the 'difficult' areas of organisational behaviour and extracts LST based models which demonstrate utility, needs and motivation being one example. Further, the author outlines how concepts such as 'boundary processes' have real importance for organisational behaviour, yet have not been addressed in current work due to the disconnection of topics such as group cohesiveness and job satisfaction.

The paper does not identify where LST *has* been applied but shows how it might be, furthering the work by Merker (1985) discussed above. The author usefully points to LST offering a basis for understanding when an organisational review is complete (i.e. all aspects of the LST framework have been covered) and additionally shows that considering the hierarchical nature of the system can help address difficult-to-assess elements by considering the system level above and/or below.

Both Bailey (1994) and Vancouver (1996) seek to compare the validity and usefulness of LST with other sociological formulations (Social Entropy Theory in the case of Bailey and broad isomorphism of models in the case of Vancouver). As with the previous papers there is no application of LST to a live case but there is a demonstration that LST can add to the types of theoretical treatments it is being compared to. Bailey (1994) calls for the consideration of LST as an integrative framework to avoid the fragmentation that over-specialisation may cause in sociology.

Vancouver, in contrast, identifies that LST is a theory in progress and that more development needs to be done before it can be generally used. A particular area for attention is consideration of what properties is it that differentiates levels in systems.

Both Schwaninger (2006) and Nechansky (2010) look to compare VSM and LST.

In Schwaninger (2006), the author makes a comparison of VSM and LST on their comparability regarding the central goal of 'viability'. Given the start point of viewing which is the better approach, Schwaninger concludes that in fact the approaches are not competitors, but exhibit complematrity.

Nechansky's later paper (which does not include reference to Schwaninger) makes an alternative conclusion that Miller's LST is a more complete description of a viable system than Beer's VSM. Particular areas additionally addressed in LST over VSM are; broader scope of LST includes simple (viable) structures that would not match VSM criteria; VSM can be derived from LST but not the other way round; VSM's central focus on direction setting and decision making are not required by LST and yet such systems are viable.

This difference of opinion may be usefully resolved by the observation of George Box *"All models are wrong but some are useful."* (Box, 1976)

The preceeding elements of this section have been considering theories, methods and tools of Systems Thinking and showing how these have (or have not) been applied in case research. The next section looks from the opposite direction. There is a growing body of research, rooted in economic geography but moving beyond it to investigate industrial 'ecosystems'; where an evolutionary model (or metaphor) of the interaction of business organisations and their co-development over time is applied.

2.5.4 Industrial Ecosystems

Industrial Ecosystems is introduced by both Lowe and Evans (1995) and Erkman (1997). These authors provide an overview of the developing concept of industrial ecologies and industrial ecosystems.

Lowe and Evens set out some key principles for industry ecology:

- All industrial operations are 'natural systems' and must operate within the constraints of natural ecosystems and biospheres
- The dynamics and principles of ecosystems offer guidance in the design and management of industrial systems
- Achieving high energy and materials efficiencies in production, use, recycling and service will generate competitive advantage and economic benefit
- The long-term viability of the planet and its ecosystems is the ultimate source of economic value

Industrial ecosystems then are industrial systems which have been redesigned to achieve a better match between industrial performance and ecological constraints – where 'waste' from one production unit is useful input to another. The Houston Ship Channel in the USA and Kalunberg in Denmark are cited as examples.

The issue with ‘design’ of such ecosystems is highlighted by the Kalunberg example:

> *“I was asked to speak on how we designed Kalundborg. We didn't design the whole thing. It wasn't designed at all. It happened over time. It's not the kind of thing you can engineer in a moment and drop in place. It takes more time. (Jorgen Christensen, VP Novo Nordisk, Kalundborg)”* (cited in Lowe and Evans 1995)

Erkman (1997) provides more historic background on the development of industry ecology ideas and cites an article in the September 1989 issue of ‘Scientific American’ (‘Strategies for Manufacturing’) as putting forward the idea that it should be possible to develop industrial production systems that have significantly less impact on the environment. The author then sets out two particular directions that industrial ecology has developed;

- Eco-Industrial parks, and islands of sustainability
- Demateralization-decarbonization and the service economy

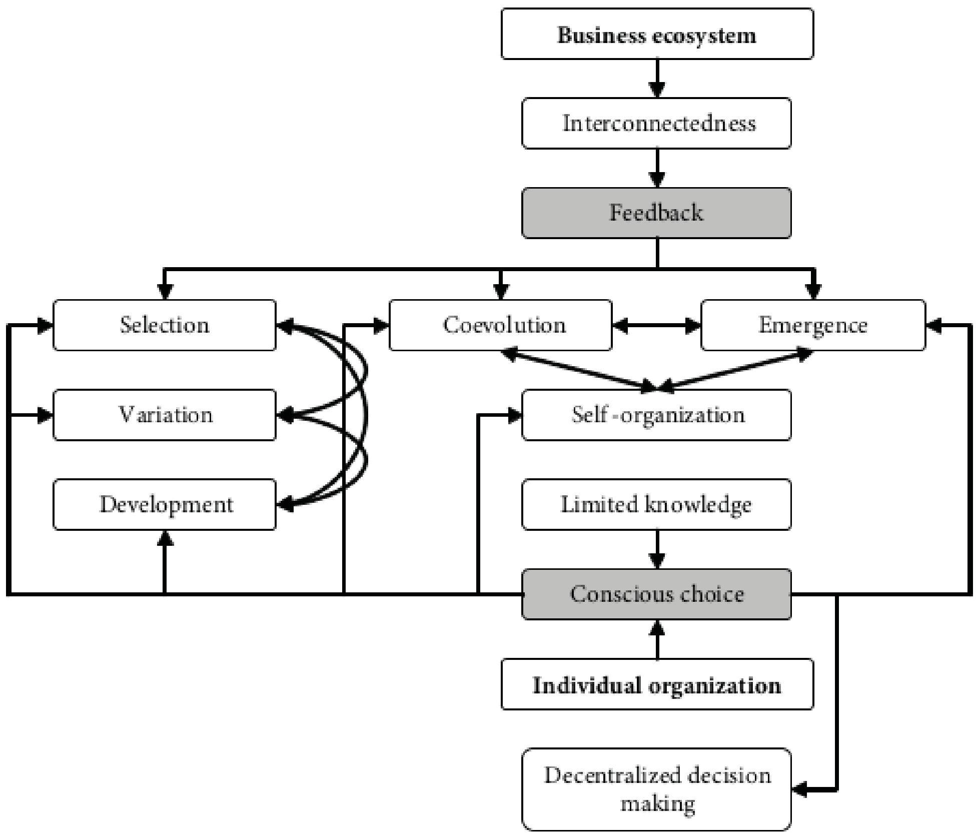
Both these papers focus on the environmental sustainability of industrial systems but do point towards a more integrated view of co-development of industry operations in a locality. They are important for this research in that they establish a systems view (albeit an *eco*-systems view) for firm interaction towards a common goal. The research highlights some of the difficulties of systems (in particular the *design* issue).

The above are primarily descriptive investigations of industrial ecosystems and later writers build upon this in development of theoretical constructs to aid investigation. This can be illustrated in Peltoniemi 2006 where the author takes the many strands of theory relating to business ecosystems and seeks overlapping concepts to help derive a theoretical framework for the study of such systems. Peltoniemi makes the point that the precise definition of ‘business ecosystem’ is still elusive, but points to a number of regular features;

- interconnectedness of participants
- interdependence of participants
- interactions are both competitive and cooperative
- scale – ecosystems have a large number of participants
- agency – ecosystem members have the ability to make their own decisions

The following schematic (figure 2.7) sets out the proposed framework;

Figure 2.7: Integrated Business Ecosystem Framework (Peltoniemi 2006)



Peltoniemi summarises the framework as follows:

> *"The integrated Business ecosystem Framework emphasizes the dynamics that follow on the one hand from conscious choice and the limited knowledge of an individual organization and on the other hand from the interconnectedness and feedback loops of a business ecosystem."*

While the framework does help pull together disparate strands, it stops short of describing how the framework should be applied to a research case.

Boons et al (2011) also propose a conceptual framework related to industrial ecosystems. The authors' focus is on the dynamics of 'industrial symbiosis'. This is (according to Chertow 2007, cited in Boons et al 2011):

> *"engaging traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity"*

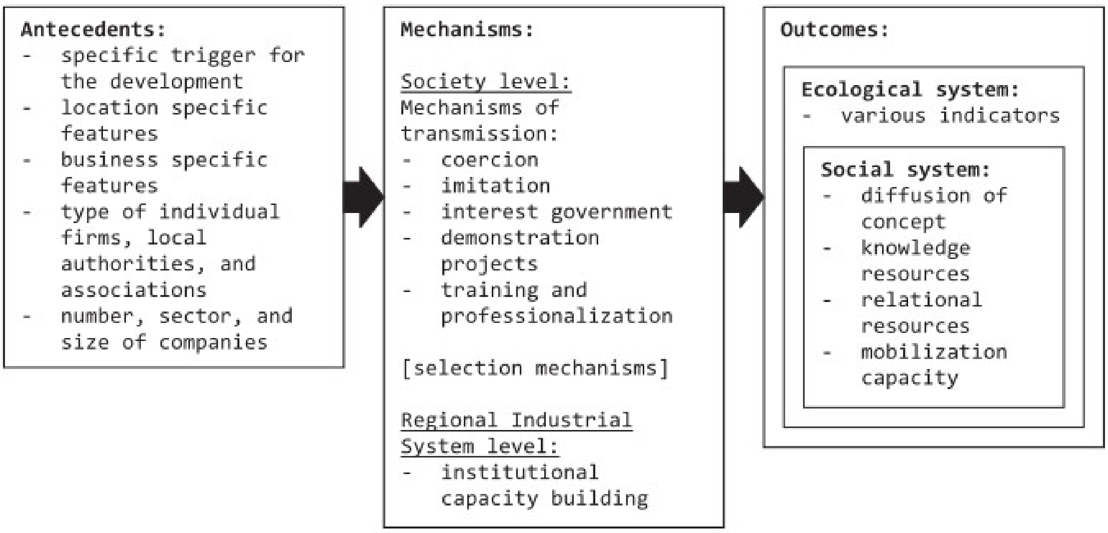
This concept of industrial symbiosis can be seen to be directly compatible with the industrial ecosystem approaches already discussed and indeed the authors use these terms in their literature search.

The authors seek to move the concept of industrial ecosystems on by taking a process view of the interactions. This affords the opportunity to consider the dynamics that underpin a regional industrial system's move to reduce the ecological footprint. They modify the geographic definition of industrial ecosystems to that of 'Regional Industrial System' (RIS) as a more generalisable concept. This is beneficial as it addresses the fact that different situations will have very different sized ecosystems and to avoid terms (e.g. eco-industrial park) that have come to have more specific meaning in other domains e.g. policy development.

The authors also add two levels of analysis for industrial symbiosis, the RIS level and additionally, the societal level. This societal level allows for elements of institutional theory (such as those discussed previously) to be introduced.

The framework is presented in figure 2.8 below.

Figure 2.8: Conceptual framework for analysing the dynamics of industrial symbiosis (Boon et al 2011)



The authors conclude that the framework has a good fit to extant literature on industrial systems and provides a way to further develop the field.

This idea of industrial symbiosis is utilised by Chertow and Ehrenfeld (2012) where the authors show how it can be applied to a number of real cases. The authors develop a 3 stage model for the development of industrial symbiosis which has resonance with the idea of industry life cycle;

1. Sprouting
2. Uncovering
3. Embeddedness and Institutionalization

The authors start with a group of 10 industrial ecosystems that have been extensively studied and which have demonstrated a level of self-organisation. They contrast this to other schemes where policy has planned ‘eco-industrial parks’ (an example from the USA is cited) but most do not come to fruition. The model is considered a first step towards understanding the life cycles of industrial symbiosis rather than an end point.

To test the utility of the model they compare a notional ‘build and recruit’ model for developing an industrial symbiosis with 4 empirical models; The Planned Eco-Industrial Park Model; The Self-Organizing Symbiosis Model; The Retrofit Industrial Park Model; The Circular Economy Eco-Industrial Park Model.

The authors conclude that the 3 stage model illuminates successes and failures of industrial symbiosis. They show that while there are many obvious and available economic benefits for companies exchanging materials with neighbours, it is difficult to plan for these advantages, especially given the important role of self-organization in early success. This reiterates the ‘design’ issue of systems.

Their theory emphasises the role of corporate actors located in a particular industrial cluster who must first find (even accidentality) economic value in initial exchanges and then become part of a set of firms whose ideas and business objectives overlap with a growing set of norms placing greater value on environmental knowledge and performance.

Further work begins to address this design issue. Korhenen and Snakin (2005) provide an approach to operationalise the industrial ecosystem idea. The authors apply the concepts of industrial ecology to the case of an industrial park in Finland. They set out some key elements of industrial ecology for consideration in their research;

- Systems and their boundaries — toward an industrial ecology
- The concept of ‘roundput’ in industrial ecosystems
- The concept of ‘diversity’ in industrial ecosystems

They show how the industrial park ecosystem developed over time (identifying Type I, Type II and Type III ecosystems with increasing interaction and maturity as time progresses) and describe the interaction of diversity and roundput and the overall ecosystem growth in scale and complexity. The authors identify the limitation that they cannot determine whether roundput or diversity actually enhance sustainability (in relation to economic resources not ongoing existence) and with what system boundaries.

This earlier paper lacks some of the insight from Boons and Chertow and Ehrenfeld work but it does build more strongly on empirical research.

More recent work by Xiaohua and Feng (2013) takes the concept of industrial ecosystems and uses it to address the issues around the development of *strategic* emerging industries. This particular taxonomy appears to be of particular relevance to the state capitalism approach of the Chinese government.

As the authors describe;

> *"The development of strategic emerging industries relies not only on breakthroughs in science and technology, but also the entire industrial supporting system which includes corporate development environment, supporting facilities and complementary products."*

The authors are particularly interested how industrial policy can support the development of strategic emerging industries. They set out a schema for the industrial ecosystem as shown in figure 2.9 below.

Figure 2.9: Composition of Industrial Ecosystem (Xiaohua and Feng 2013)

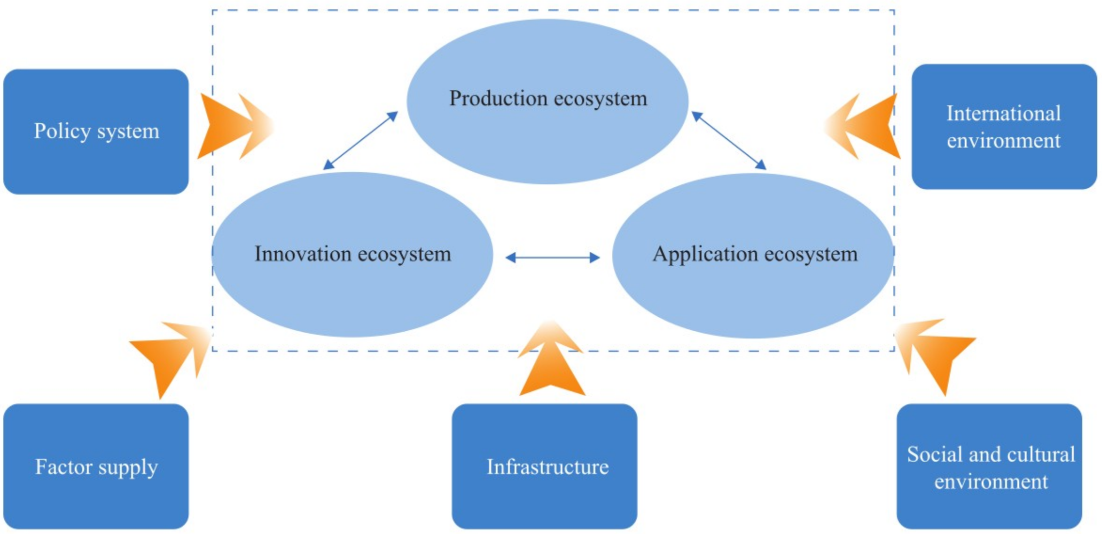


Figure 1: Composition of Industrial Ecosystem

They highlight strategic emerging industries as having the characteristics of radical innovation, uncertainty and complexity and are strategic as they are the focus of competition in the global market. They consider that countries which take the lead in setting up complete industrial ecosystems will occupy favourable positions in strategic emerging industries.

The authors conclude that these characteristics of uncertainty and complexity require external support (in the form of policy) and go on to set out explicit roles for government e.g. to promote the establishment of an institutional environment and incentive mechanism which are conducive to innovation; to allocate government R&D funding in a competitive and fair manner.

The paper gives a very strong insight into the mindset of policy driven industry development, but it fails to address the 'design issues' laid out by earlier authors, nor does it give any mechanism for ensuring e.g. 'competitive and fair' funding allocation. It is relevant as the authors show a natural move from the consideration of groups of companies (from disparate industries) interacting to further a particular common goal (improved environmental performance) to groups of companies interacting to further the development of an industry. However it is not clear whether the authors directly intend to progress the ideas of industrial ecosystems towards emerging industrial systems, or whether they are conflating the two topics.

The above papers introduce a number of concepts important for this research; interaction of disparate organisations towards a common goal, the difficulty of purposeful design for complex and adaptive systems are 2 examples; however the ecosystem element is particularly focussed on environmental performance as the linking driver rather than emergence or viability of specific industries. There is a related body of literature which takes a similar approach but is more concerned with the co-evolution of supply networks to meet a variety of goals and hence offers more direct connection to this research, that of Supply Chain Networks (also referred to as Supply Chain Ecosystems). This provides a more robust bridge between the investigation of multi-industry industrial ecosystems approach and the understanding of a single industry as an ecosystem.

Supply Chain Networks

Early work in this area comes from Srai and Gregory (2008). In this first paper the authors set out to explore how the configuration of supply *networks* (this author's emphasis) impacts on the capabilities of these networks. This work builds upon a development of the 'competing firms' model exemplified by Porters 5 forces (Porter, 2008) to a 'competing supply network' perspective.

The relevance for this research is that it goes beyond considering individual firms and their capabilities and begins to look at mapping the whole of a supply network. The authors identify that the establishment of meaningful boundaries for a supply network in focus is a critical and non-trivial feature.

The authors develop mapping techniques in support of this exploratory research and find that;

- Their tools are practical in use and give new insights
- Network configurations are different for different firms
- Mapping the configurations is necessary to understand potential transferability – there are indications that configuration is significant for capability development
- Network configuration is a key enabler of supply chain capability and may impact the operational process maturity required
- Advanced performance does not always correlate with advanced Supply Chain Management processes.
- Supply network re-configurability concepts emerging from the research provide potential new routes to network transformation

The authors conclude that the observed network configurations '*suggest the potential for developing and integrating these concepts as part of a broader framework on "industrial structures".'*

They also note that such research *'is complicated by the difficulty in defining system boundaries and further work in network definition may contribute to the development of supply network theory.'*

This is a recurring theme in systems literature and suggests areas that will need to be considered for the empirical portions of this research.

Going beyond the difficulties of systems approaches to supply networks, the utility of such an approach can begin to be seen. This can be demonstrated in the work of Lorenz et al (2013) where the authors look at the effect of emerging market characteristics on supply network design. In their literature review they make explicit reference to the need to treat supply networks as complex adaptive systems that can evolve and self-organise over time. This begins to address the previously identified issue with the use of 'complexity' as a metaphor within business literature (rather than a well-defined and defended theoretical construct) by focussing on particular aspects of complexity i.e. complex adaptive systems.

Lorentz et al (2013) identify that the capability / capacity for evolved and self-organising structure is highly relevant in an emerging market situation where the underlying context is highly uncertain and rapidly changing.

The particular context that the authors investigate is the internationalising of food supply chains. They suggest that institutions (trade regulation), and primary (food producers) and supportive actors (logistics providers) may often be considered as constraints to the system, and appear to have a dominant role in determining the adjustment of supply network's structural attributes (e.g. in-sourcing activities, partnership agreements in place of transactional contracts). The impact of external influences (to the supply network) is seen to either convergent (networks tend towards similar structure) in response to opportunity; or divergent (many alternative forms are seen) in response to constraints.

This research shows how supply chain change over time can be conceptualised in terms of system responses.

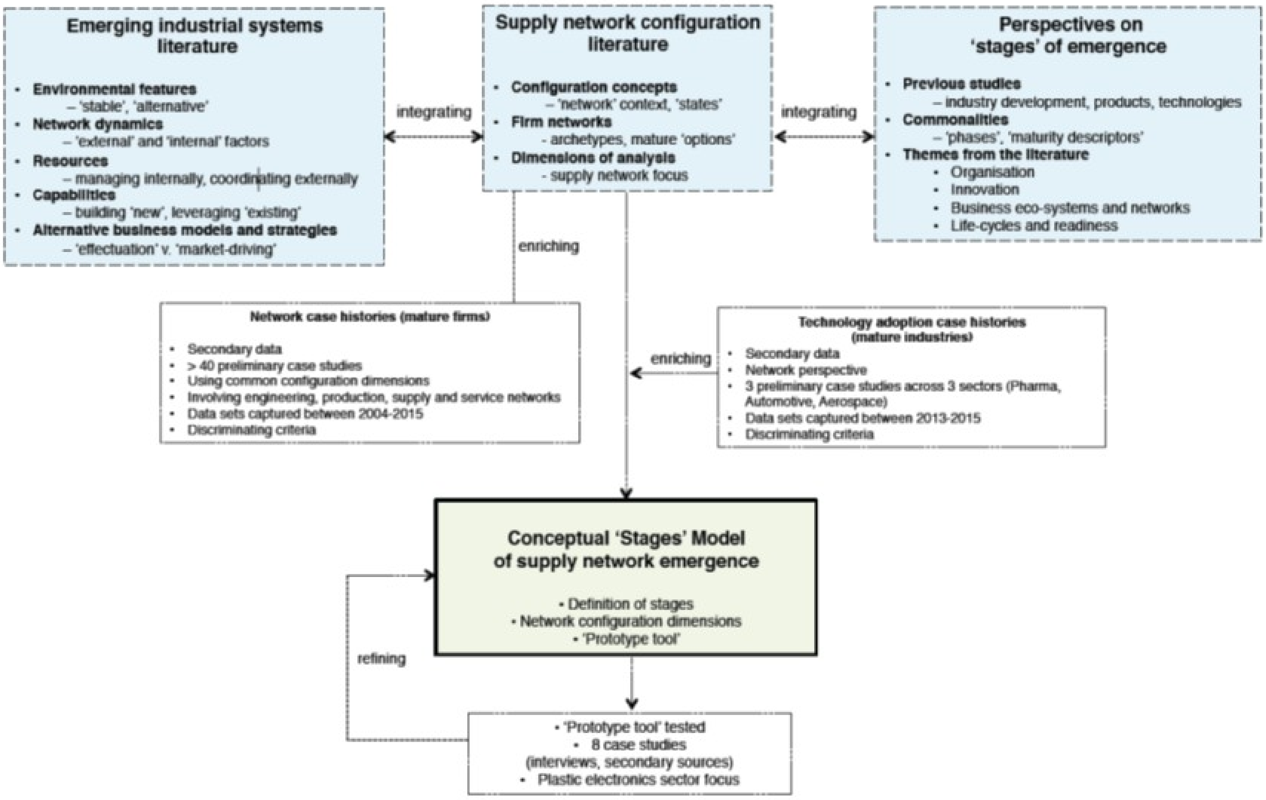
In Harrington and Srai 2017, the authors' focus gets closer to the emerging industry context of this research. The authors examine the dynamics of supply network emergence in technology commercialisation and develop a 'stage' model of this evolution. They consider different modes of emergence for supply networks during the process of technology commercialisation, examining how key actors and enterprises design and re-configure their existing and emerging networks.

Of particular interest is the observation that existing network analysis models are based around mature industries and that work is required to better fit the emerging industry case. The authors suggest that their work has practical applications for managing critical resources during the emergence stage.

The authors identify the importance of addressing a broad portfolio of characteristics when considering an emerging industry system including *"context, resources, activities, processes, actors, and interdependencies that support the creation and delivery of products and services"*.

They summarise the literature as follows:

Figure 2.10: Emerging Industrial System Literature (Harrington and Srai 2017)



The research looks at a number of cases to support cross case analysis obtaining its primary data from interview with involved personnel. The focus of this work is on the co-evolution of the supply networks and the industries they are part of, rather than of the industries themselves. It does look at the role the supply networks play in successful emergence of the 'host' industry. These industries are mass manufacture rather than CoPS in nature.

The authors (in common with earlier contributions) highlight the difficulty of researching emerging industries and the need for more case studies.

While this literature does not address the emergence of new industry directly it is congruent with the emerging themes of systemic behaviour, whole network unit of analysis, design of (or at least beneficial action towards) emergent industrial systems. The literature is separate from that of industry ecosystems in that it is not looking at environmental performance, although that may be of relevance in specific cases, but at performance of supply networks in general.

2.5.5 Systems Engineering

The final brief element considered in this review of existing knowledge arises from this author's discussions with Systems Engineering practitioners on the topic of addressing 'wicked problems' - cyber-security being the context of the discussion. The congruence of this research and the engineering domain goes beyond the word 'system'. In 'wicked problems' there are as many issues of defining the problem as there are technical challenges in solving it. 'Wicked problems' in systems engineering are described as situations to be managed, not solved (Sillitto 2014, p22).

In 'Architecting Systems' (Sillito 2014) describes the idea of designing for intermediate structures to allow the 'right' (suitable variety, effective responses, timely responses) final structure to emerge (or indeed continually adapt to the circumstances). Intermediate structures may be conceptualised as an organisational framework to be built upon as the system develops or may considered as a scaffolding that is subsumed and disappears as the system progresses.

The benefit of Systems Engineering perspectives for this research is that they are, by definition, *design* oriented. The goal of the activity is to achieve a pre-defined 'good outcome'. This chimes very strongly with implicit goal of the original research question – to 'create' a new, viable industry.

In Sillitto et al 2018, the authors make the case for Systems Engineering to become;

> *"a foundational meta-discipline that supports and enables collaboration between all the disciplines that should be involved in conceiving, building, using and evolving a system so that it will continue to be successful and fit for purpose as time passes"*

The potential for application in this case shows how this might come about.

2.5.6 Summary of Systems Thinking

Systems thinking does not directly address emergence of new industry, but the literature does provide a number of conceptual structures that are helpful when undertaking the study of an emerging industry.

Conceptualising industry as a system

Identifying industry as a system potentially helps the definitional issues of particular industries that occur when researching with industry as the unit of analysis. Systems have purpose; systems have blurred boundaries; system descriptions are hierarchal.

Emergence is a Systems characteristic

The broad aim of this research is to better understand emergence of a complex product system industry. 'Emergence' from a systems stand point describes an aspect of the overall behaviour of a system that cannot be predicted from the behaviour of its constituent elements (Checkland, 1999 pp74).

Systems Tools

The investigation of system behaviour that can't be predicted from those of its constiuent parts requires a different analytic approach to reductionism. Systems Thinking has an established 'tool set' that can be applied

Concept of Viability

Systems Thinking adds the concept of 'viability', the ability of a system to recreate itself (Beer, 1984). This adds to the idea of system emergence as a desirable characteristic for an industry i.e. not only does the industry emerge, but it continues to function for a protracted time. This property is surfaced in the literature reviewed next.

2.6 Case Literature relating to Industry Emergence

2.6.1 Overview

The following table summarises the recent case literature on emerging industries and gives an indication of the central focus of each paper, the type of data used in support of the research, the broad domain the research encompassed, whether the paper discusses the need for studying emerging industry (EI) and whether the paper addresses the issue of industry definition.

Table 2.5: Case study on industry emergence - selected papers

Pub. Year	Author (s)	Focus	Data	Business / Economics / Whole	Need for E.I.	Ind. def.n
2007	Jordan et al	Country difference impact on industry development	Survey	Business	N	N
2009	Vasi	Social Movement Organisations & Industry growth	Historical	Economics	N	N
2010	Mezias et al	Creating legitimacy for new industry	Historical	Economics	N	N
2010	Espinoza & Vredenburg	Industry emergence in different contexts	Interview	Whole	N	N

Pub. Year	Author (s)	Focus	Data	Business / Economics / Whole	Need for E.I.	Ind. def.n
2011	Peltoniemi	Reviewing industry life-cycle	Historical	Economics	Y	N
2012	Fixson & Lee	Knowledge creation during emergence	Historical	Business	N	N
2012	Funk	Standards development in new industries	Published, Interview	Business	N	N
2013	Shi et al	Firm nurturing of industry ecosystem	Interview	Business	N	N
2013	Lubik et al	Strategy drivers in emerging industry	Interview	Business	N	N
2013	Xia & Minshall	Investment patterns in emerging industry	Historical	Whole	N	N
2013	Klitkou & Godoe	Triple Helix driver for emerging industry	Historical	Whole	N	N
2014	Ruan et al	Government's role in disruptive innovation and industry emergence	Interview	Whole	N	N
2014	Ford et al	Supply / demand dynamics in industry emergence	Interview	Whole	Y	Y
2014	Prno & Slocombe	Systems framework for social licence	Observ-ation	Business	N	N
2014	Agarwal et al	Firm shake-out and innovation processes during emergence	Historical	Economics	Y	N
2014	Tanner	Impact of region suitedness on 'regional branching'	Historical, Interview	Economics	Y	N
2015	Gupta et al	Entrepreneurial activity (bootstrapping) during emergence	Historical	Business	Y	N
2016	Tanner	Emergence of new industries: relatedness to regional knowledge bases	Historical	Economics	Y	N
2016	Mezias & Schloderer	Institutional impacts during emergence	Simulat'n output	Business	Y	N
2016	Potstada et al	Alignment processes in emerging industry	Survey	Business	N	Y
2016	Harrington & Srai	Supply Networks in emerging industries	Interview, mapping	Whole	Y	N
2017	Matti et al	Policy mix and its impact on industry evolution	Interview, published	Economics	N	N
2017	Edman & Ahmadjian	Impact of 'empty categories' on industry emergence	Interview, published	Whole	N	Y
2017	Seidel & Greve	Social emergence of industrial ecosystems	Document	Business	Y	N

Pub. Year	Author (s)	Focus	Data	Business / Economics / Whole	Need for E.I.	Ind. def.n
2018	Dodd et al	Factors that stall an emerging industry. Optimists v pessimists	Interview, published	Business	N	N
2018	Carlos et al	Social Movements	Historical	Economics	N	N
2018	Aspelund et al	Why the solar PV industry was able to emerge in Norway	Historical	Whole	Y	N

The literature highlighted above addresses the topic of industry emergence from a broad set of domains including; evolutionary economics, economic geography; sociology, institutional theory, social movements; business strategy, entrepreneurship; and industrial ecology. These can be separated into groups of papers with a basis in economic analysis (8 off), a business focus (11 off) and a whole industry focus (8 off).

Less than half the papers are based on research that includes interviews with participants. The data source (document versus interview) for the 3 broad groups were noticeably different. The papers dealing with the industry as a whole tended to be interview based (5 out of 8); those dealing with economic analysis tended not to use interview (2 from 8) and the research papers looking at business perspectives were in between (5 from 11).

Papers from prior to 2014 did not make any explicit exposition on the need to research industries in their emergent stage with a single exception (1 from 11), the review paper by Peltoniemi (2011), which addresses this issue and makes a direct and clear call for more research into the phenomenon.

This is in stark contrast to the papers from 2014 onwards in which 9 of the 16 papers make explicit reference to the need for research into emerging industry. These papers reference Peltoniemi 2011 and earlier writers (e.g. Porter 1980) in their identification of the need but no indications are given why there should be such a change in the recognition of this need in this time-frame.

It can also be seen that few (3 from 27) papers address the definition of industry for their research. This may be an impact of the studies all being post-hoc when the emerged industry is readily identifiable.

The following sections look at the knowledge developed in the the various domains identified.

2.6.2 Economic analysis

Looking at the papers which broadly address the economics analysis (Vasi 2009, Mezias et al 2010, Peltoniemi 2011, Agarwal et al 2014, Tanner 2014 & 2016, Matti et al 2017, Carlos et al 2017) there are a number of common elements.

Legitimacy

Vasi (2009), Mezias et al (2010) and Carlos et al (2018) all address issues of legitimacy and its impact on industry emergence. Vasi (2009) and Carlos et al (2018) have a common focus on the role of social movements in the dynamics of an industry and both focus on the wind energy industry, albeit in different territories (Vasi looks at an international dataset and Carlos et al. focus on the US industry).

Vasi (2009) extends the theories on social movements to show how they can effect change at an industry level. This builds on previous work looking at social movements in cultural and organisational change. The qualitative analysis identifies a number of factors 'causing' wind adoption in individual countries;

- level of development in the territory (broadly economic and technical development, based on the UN ranking of less developed / developing / more developed nations)
- the levels of natural resources available (specifically wind strength in the national market),
- the strength of environmental organisations in the territory (evidenced through documentary secondary data)

Vasi also draws conclusions on the social movement mechanisms that drive this causality. The author identifies the following 3 mechanisms:

- the shaping of policy (German feed-in tariffs are an example)
- the shaping of entrepreneurs views on the industry (building legitimacy)
- the growing of consumer demand (another form of legitimacy).

Carlos et al (2018) focus their work on how social movements can inspire the emergence of new *markets* (this author's emphasis) by drawing attention to problems with the state 'as is'. The research is conducted on a historical dataset for the US wind industry and associated documents and uses a hypothetico-deductive approach to draw conclusions.

The authors of this research find that social movements help industry emergence through a series of mechanisms:

- strategic framing (helping legitimisation by providing a consistent rationale for the *market*)
- resource mobilisation (helping to build and extend the population that wants to be part of the movement)
- political opportunities (the development of a legitimate market and the increasing population of ‘involved’ groups and individuals increases the opportunity for political action)

They also deduce that the effect of social movements is attenuated as the markets expand, and that simultaneously the importance of natural resources is accentuated. Finally they conclude that there is a role for public policy to reduce risks for entrepreneurs.

Vasi and Carlos et al are broadly compatible. Both research studies conclude that social movements have a measurable (positive) impact on the emergence of wind power. The work of Carlos et al is a specific case of the Vasi work in that it is only looking at a single country, and so two of Vasi’s factors (state of development and level of wind resource) are held constant in the Carlos et al work. Outside this there is congruence on the conclusions of shaping entrepreneurs view and growing consumer demand (Vasi) and strategic framing and resource mobilisation (Carlos et al).

The third study with a focus on legitimacy is that of Mezias et al 2010. In this work Mezias et al looks at the process of *creating attention* and *creating favorability* [sic] as seen in the emergent film industry of the USA between 1894 and 1927. The objective is to investigate the processes that help overcome legitimacy barriers for a new (or emerging) industry. It is explicitly looking at the role of social context in industry emergence (and evolution).

The authors suggest that key mechanisms that provide this attention and favourability are the dissemination of information to broader audiences and the meeting the expectations of potential constituents of the industry. Their argument is that participants and advocates for a new industry must capture the attention of the wider economy (through its actors) and generate favourable perceptions of the new / emerging industry. They investigate whether increasing firm experience and ties between firms helps to build the attention and favourability.

The study is again conducted with a hypothetico-deductive approach, this time using data available on the industry and historical records (e.g. press articles) on the external views of the industry. The authors conclude that *attention* increases as firms in the industry build experience and that *favorability* also increases with this experience. They also show a negative impact on *favorability* of the industry as ties between firms increase.

Industry Life Cycle theory

Peltoniemi 2011 and Argawal et al 2014 provide papers that are focussed on industry life cycle theory (this theory is explored in more detail later). Peltoniemi contributes a review paper on the state of Industry Life-Cycle (ILC) theory and Argawal et al study the regularity of 'shake-out' in the emergence phase of industries. Their particular interest is why some firms seem to abandon industries as the sales begin to rapidly grow.

The Peltoniemi paper (Peltoniemi 2011) considers the state of literature on Industry life cycle (ILC) as a whole. This is a comprehensive review – although not formally following a systematic review process (after Tranfield 2003) – that down-selects from a large number of potential papers (216) based on the inclusion of key writers (Abernathy, Utterback and Klepper) and the number of citations (greater than 100). This dramatically reduced the reviewed papers to 7 papers that were then used as a core and citations were followed upstream and downstream to conduct the review.

The focus of the author's discussion is very much on comparative entry and exit rates of firms to industry as a determinant of the different ILC stages. The author identifies that industry emergence is the outcome of a technological opportunity that encourages the entry of a large number firms (to the industry) and the introduction of many product variations. 'Discontinuity', either through a disruptive technology or a newly available market, is seen as a key branching point for new industries. During the emergence stage it is the entrepreneurial regime of innovation that is dominant. Firm entry levels are high – although firm exit rates may also be high so net growth in firm numbers may be low. The emergence stage is typified by entry rates that are significantly greater than exit rates.

The author concludes that an industry has 'emerged' when the focus of research and development (or innovation) activity has moved from *product* to *process*. The identification of a 'dominant design' plays a role in this shift. Post emergence 'regularities' at this stage in ILC include industry 'shake out' where there is a large contraction in the number of firms involved in the industry (firm entry rates are significantly lower than firm exit rates).

Peltoniemi's paper identies the following key themes in ILC literature:

- Firm entry and exit rates (as explained above)
- Change in the nature of innovation (product to process)

- Survival rates of firms (e.g. is there a first mover advantage?)
- Entry timing (e.g. when should a firm enter a new market)
- Levels of innovativeness in firms. The combined literature indicates that a high level of innovativeness is an 'insurance' against failure.

The review shows that all the industries covered by ILC research are product focussed, and mass manufacture, with the possible exception of ship-building. This leads the author to consider a potential research gap in the 'special cases' of;

- Complex Products or Services (typically capital goods – reviewed in more depth later in this chapter)
- Service Industry
- Cultural Industries

It is notable that the combined scale of the 'special case' industries far out-weighs the researched industries in a typical developed economy (UK manufacturing is 10% of the GDP, service is 80% [https://www.ons.gov.uk/economy/grossdomesticproductgdp]).

The author then proposes the following research questions for investigation:

- Qualitative change of entry / exit as industry ages
- How is sufficient performance determined (ability for late entrants to outperform existing)?
- Is the early entry benefit from accumulation of capability or better firms entering earlier?
- Importance of pre-entry experience (technological, complementary competence)?
- Does innovation fuel success or does success fuel innovation?

Argawal's paper has a significantly more focussed lens on ILC theory and explores the phenomenon of 'shake-out' which is considered to be a characteristic of an emerging industry moving into the growth stage. By looking at historical data on 24 new product industries the authors identify an earlier 'mini shake-out' which suggests that firms are exiting the industry just as it becomes profitable.

The paper seeks to explain this phenomenon by researching 2 specific emergent industries – handheld computers and digital cameras. This element of the research is case study research conducted on published documents but without interviews.

The authors identify 2 factors which seem to combine to govern this early mini shake out, the impact of unmet expectations (which they further characterise as ‘asynchronicity’ - the delay in results from input efforts) and the level of strategic importance to the organisation.

This can be put in colloquial terms – *‘if we’re working hard and nothing seems to be happening, and it was never that important to the company, let’s give up’*.

This is expanded in a 3 x 2 matrix shown in table 2.6 below:

Table 2.6: Why do some firms abandon an emerging Industry? (Argawal et al 2014)

	Different expectations about customers	**Different views of strategic importance**
Industry-level drivers	Shared industry beliefs about customer needs and technologies create overly optimistic beliefs about the market opportunity Widely differing forecasting methodologies and predictions are available	The emerging industry is only viewed as a diversification opportunity
Firm-level drivers	The firm has no history of investing in emerging industries The firm only targets large market segments	The emerging industry is not core to the firm’s identity
Intra-firm drivers	Top management and functional managers have very different perceptions of the market	The personal stakes for managers are not aligned

The authors conclude by identifying that research into firm entry and exit is skewed towards decisions about industry entry and that industry exit is treated as an economic necessity. Their work shows that there are also qualitative decisions (whether operational, tactical or strategic) being made about industry exit.

Evolutionary Economic Geography (regional branching)

The next pair of economics based papers is by Tanner (Tanner 2014, Tanner 2016) which are rooted in the domain of evolutionary economic geography. Both papers look at the emergent fuel-cell industry to better understand the process of ‘regional-branching’. ‘Regional branching’ is the term given by Boschema and Frenken (cited in Tanner 2014) to the process whereby new industries tend to emerge where the already established industries are technologically related to the new one. The author states that the process has been empirically confirmed in regional studies of Sweden and Spain, and in the case of the fuel-cell industry in Europe.

In the first paper Tanner outlines the research need to look at the emergence on new industries. The author identifies the concept of regional branching as providing a ‘temporal scope’ to new industry emergence that has previously been lacking in evolutionary economic geography. The author indicates that post-emergence studies will have difficulties in grasping the essence of how and why industries come into being.

Within this context the author puts forward a number of areas that need to be investigated. The first is a lack of a thorough understanding of the mechanism that drives regional branching. A number of activities are argued for including:

- firm diversification
- entrepreneurial spin-offs
- labour mobility
- social networking

Prior research has shown entrepreneurial spins-offs to be a driving mechanism is some industries but further research is required.

Secondly the author identifies the fundamental claims of branching mechanisms need to be examined as the idea of ‘technological relatedness’ is not clearly defined. The paper seeks to examine whether technological relatedness is *always* the underlying logic of regional branching.

Finally the author explains how the regional branching thesis moves beyond the cluster theory focus on specialisation to also consider the role of supporting networks (universities, research institutions etc.) that are in ‘cognitive proximity’ to the pre-existing industrial structure. Thus, a better understanding is useful to regional policy makers.

To carry this out, the author follows a grounded approach to a specific industry (fuel-cell development in Europe). The goal is to avoid too much pre-defined structure to the understanding developed from engaging with the case. The research itself uses historical patent data to investigate the development of the industry and marries this with a series (7 off) of interviews with firms and institutions involved in the industry.

The author finds that in this case the emergence of the industry is driven by firm diversification. This adds to the previous work which identified entrepreneurial spin-offs as the mechanism but does not contradict it. The study also corroborates that regional branching relies on the availability of knowledge within the geography (from universities etc.) and suggests that the processes are more complex than previously posited and thus that regional branching may arise even though there is no pre-existing economic activity within the base technology of the new industry.

Policy Setting

The final paper in the economics group (Matti et al 2017) looks at the impact of the mix of policies in a country on an emerging industry. The mix covers policies at different regulatory levels i.e. super-national, national, regional (local). The case being considered is the successful emergence of Spain's onshore wind industry – both as a producer of electricity and as a technology producer i.e. the development of a Spanish wind turbine supply chain.

The focus of the research is on understanding to what extent policy instruments designed at different levels can be coordinated in an '*organic process*' (the author's own words). The author makes the point that focussing at a single level of policy will limit understanding (organisations always feel the impact of all policy instruments); and that the consequence of the policy-mix coming from a variety of sources is an *emergent* (this author's emphasis) entity rather than a pre-planned one.

The research is based in historical documentation (performance indicators of the wind energy sector, patent data, research and development performance) supported by interviews with EU officers, private and public R&D staff and regional government officers (12 off).

The research finds that the emergence of the Spanish wind generation industry was driven by a complex interplay of policy instruments at different levels. As an example, the development at a national level of an attractive Feed-in tariff scheme and a long-term vision encouraged market deployment. Regional level industrial initiatives built upon this to encourage industrial developments (through cross-sector agreements).

The research points to the need for coordination mechanisms to ensure positive outcomes from the inter-play of policies in the policy-mix.

2.6.3 Business Focus

11 of the case study papers research the topic of industry emergence from the perspective of individual firms. They can be further split into groups of papers which consider strategy (4 off), the business environment / ecosystem (3 off), entrepreneurial activity & innovation (2 off) and the topic of legitimacy and institutional theory (2 off).

Strategy

The papers of Funk (2012) and Potstada et al (2016) look at the ways in which firms can address uncertainty through strategic activity. The approaches investigated differ in terms of the internal or external drivers that might address this.

Funk (2012) investigates the ways in which ‘standards’ emerge in a developing industry and how this relates to the concept of ‘critical mass’. The author distinguishes between initial direct industries where a critical mass of users is needed (e.g. telephones, social network platform) and indirect network industries where the critical mass is of complementary products. The standards referred to include interface standards, communication protocols etc. These may be ‘open’ standards which are freely available, or proprietary where the standard is owned and maintained by a single legal entity and some form of rent is charged for its use.

In particular the research looks at the Japanese mobile internet industry and follows a qualitative case study methodology in which published information is added to a large body of interview material which the researcher had collected over a number of years. Some key concepts the paper expands upon are those of complex systems / simple products. Complex systems are identified as having more sub-systems than ‘non-assembled’ simple products. The more complex the system, the greater the number of potential interfaces. The author is interested in the drive towards standards for these interfaces.

The paper looks at mobile internet industry as a whole and identifies the following mobile internet offerings for investigation;

- entertainment (games)
- text-based internet sites
- publishing
- location based services
- retail and ticketing systems
- broadcasting

The author finds that the way standards come in to being is ‘messy’ (as should be expected from a complex system). Some standards were designed but many emerged as the industry developed adding more options to the industry.

The author concludes that strong ties are required between the service entrepreneurs and the hardware providers to help promote any future interface standards required for new services. A role is outlined for government to promote the development and adoption of standards to help accelerate the growth of industries such as mobile internet.

Potstada et al (2016) look at collective industry action from a different stand point. The authors were embedded within a European Union funded project looking to support the emergence of digital fabrication (3D printing etc.).

The paper's focus is on how firms deal with strategic uncertainty in an emerging industry via the strategic concept of alignment (all participants going in the same direction) and looks at how a European consortium project DIGINOVA achieved this.

The authors proposed that uncertainty in this emerging industry can be tackled through 'alignment intelligence'. The mechanisms for this included tools such as

- roadmapping;
- providing decision aiding information;
- working beyond borders of a single organisation in anticipation of collaboration;
- including demand-side information.

In the DIGINOVA project the objectives were;

1. A process of identifying and ranking the top opportunities for DF and their estimated time to market.
2. A process of identifying and further articulating key technology challenges.

The research methodology was that of participant observers and included a qualitative analysis of the whole DIGINOVA consortium via survey. One of the contributory elements of uncertainty that the authors identified was the lack of a coherent "techno-economic system that can be labelled 'digital-fabrication industry'" i.e. what is the industry that is emerging?

The authors found that DIGINOVA could provide the alignment information being sought but that the support was passive in nature. That is to say it did not actively drive the direction of the industry. To be active, the authors propose that an action-based roadmap is required to set out activities that would move the organisations (and nascent industry) towards desirable goals.

The other pair of papers that also look at the strategic action of firms in an emerging industry (Platts et al 2012, Dodd et al 2018) focus on phenomena around the strategic orientation of the firms.

Platts et al 2012 investigate the strategies used by a group of companies (25 off) in 7 different emerging industries. Their paper's start point is the impact of technology-push versus market-pull in manufacturing start-up firms in emerging industries. The authors underline the economic importance of investigating emerging manufacturing industries as a path to replacing declining traditional manufacture. The also state a lack of research into emerging industries as a motivation for the research.

The research is conducted via case study with an pre-existing structure (questionnaires and strategy maps) to support data collection and analysis. The study is post-hoc (companies are selected in industries that are recognised as having emerged) but makes a selection choice to look at firms less than 15 years old.

While there has been prior research of the strategic stance of start-up companies that established market-pull as the dominant stance (the authors cite Utterback 1974 and Langrish et al 1972 for a circa 65% market-pull stance), this work found the opposite – a marked initial preference for technology-push in the sample – 60% technology-push.

The work also found that firms tended to follow a change trajectory towards the alternative stance as they matured e.g. technology-push towards market-pull and vice versa and that this change was triggered by external circumstances (new partners, investor pressure for technology-push and need for improved processes or supplementary product for market-pull). This expands on existing literature that suggests a more static approach to strategic orientation.

The 2 change trajectories (technology-push to market-pull and market-pull to technology-push) are elucidated via causal map-like diagrams.

Dodd et al's recent paper (Dodd et al 2018) seeks to understand why an emerging industry stalled through the qualitative review of companies in 3 separate country contexts. The industry the authors focussed on was that of aviation biofuels. This industry was of interest as despite a growing focus on the 'greening' of transportation and the global aviation industry's endorsement of the technology, aviation biofuel industry is seen to be stalling. Their focus is on the impact of industry prospects (optimism versus pessimism) on the industry's progress towards commercialisation. The authors identify that existing literature '*did not provide clear guidance as to the desirability of either optimism or pessimism for actual future performance'*.

The authors consider their focus on gathering qualitative evidence of *industry outlook* (their emphasis) optimism and industry pessimism through interview to be an important new contribution. In particular the evidence allows the strategic mindsets of firms' managers to be compared and contrasted with other stakeholders in the industry. The divergence of views is considered to be a mechanism for stalling the industry.

The research itself is conducted via a mix of publicly available documents and interviews with personnel in 58 organisations across 3 geographic markets (USA, Germany and Australia). The study aimed to contact every biofuel company in the target markets.

The research found that there were very different views of the industry outlook between the public 'face' (via published documents) and the interview participants. In particular, the public face was more optimistic than the view expressed by participants in interview.

As well as this discrepancy between 'published' and private views, the authors established a link between the level of optimism and strategic mindsets of the participants.

- Industry optimists were focussed on strategic action such as diversification, demand driven research and development, learning orientation
- Industry pessimists placed more focus on premium pricing, government intervention, developing economies of scale

Firm Environment / Business Ecosystem

While the last 4 papers were investigating the strategic stances of individual firms and how these firms might impact on the emerging industry they were involved with, the next group of 3 papers investigate how the businesses co-evolve with their business 'ecosystem' - a firm used explicitly in 2 of the papers.

Jordan et al (2013) conduct a cross-case analysis of French and Australian wine companies to investigate the highly successful emergence of the Australian wine industry. The authors research goal is to extend the pre-existing literature relating business performance to strategic and market orientation to include the external environment of the firms. They focus their investigation on the differing national legislation and infrastructure of the two nations and on the level and nature of inter-organisational collaboration.

The work was conducted via a survey of French and Australian wineries (82 responses from France and 63 responses from Australia). The survey itself was developed following in-depth interviews of

2 wineries from each territory. The results allowed an analysis of variance between responses that identified significant differences, viz;

- Australian companies have a different market and strategic orientation stance compared to French – they are more customer focussed and more growth oriented.
- The Australian industry is more cohesive and simpler than France.
- The Australian industry environment more supportive of innovation and entrepreneurship than France.
- Australian industry thinks the legislative environment is simpler than in France

The authors conclude that the external industry environment is an additional determinant of business performance, along with the internal factors of strategic and market orientation. They also identify an initial indication that collaboration between companies is more important than competition when seeking to enter and grow export markets. Although they do not use the term business ecosystem, their description of this wider environment of collaborators, legislative instruments, peer attitudes is a close match.

Shi et al (2013) explores the ways in which individual firms enhance the business ecosystem to support the development of emerging industries through addressing uncertainty. The research is conducted within the personal computing and mobile computing business ecosystems which, at the time of writing, were converging.

The authors cite Moore (1996) in describing a business ecosystem as;

> *an interdependent economic community including industrial players, governments, universities, and other relevant stakeholders, who co-evolve with each other to create and deliver value.*

They further identify the need to describe business ecosystems in contrast to ‘industry’ as the concept of industry fails to represent the importance of cross-industrial collaboration. The authors then discuss the phenomenon of industry convergence where the boundaries (‘*blurry margins’*) of individual industries begin to overlap and then merge allowing the emergence of new industries – in this case the convergence of mobile phones and personal computing the produce the mobile computing ‘ecosystem’.

The research is conducted as a cross-case comparison of 7 firms. Each case is a firm and its ecosystem partners. The primary data collection is via interview with secondary data extracted from media searches.

The authors find that firms within business ecosystems have developed two kinds of strategies to deal with the uncertainties of emerging industry;

- core-firm platform strategy where the technology developers (who are often far removed from end-users) encourage partners to develop offerings on their platform
- niche-firm supplementary strategy with an integrated supply chain where firms who don't 'own' a platform create alliances with customers to co-evolve their offering with specific platforms

By using such strategies, firms together follow a three-step process (adjustment – adoption – convergence) to help nurture the emerging industry.

The final piece of literature of the business ecosystem is Seidal and Greve 2017. This book chapter provides an overview of how the evolutionary processes of novelty, growth and formation shape both organisations and the ecosystems they exist within. The authors' domain is that of organisational sociology and the growing work taking an evolutionary perspective on organisational change.

The authors explore the analogy of evolution as pursued by organisational sociology as it relates to the phenomenon of 'emergence'. They draw particular attention to the difference between '*speciation'* (in which new forms emerge due to random variation and drift) and '*natural selection'* (in which the new forms occurrence is less random with the environment promoting survivors).

The principle contribution from this review work is to highlight the complexity behind the idea of emergence and to identify the necessary elements of;

- creation of novelty
- growth to a salient size
- formation into a recognisable social object/process/structure

The authors argue that the post-hoc nature of research into emergence in industry leads to all the cases being 'special' in some form. They push for researchers to consider a more 'grounded' examination of emergence to advance knowledge of this phenomenon as it relates to organisation and organisational ecosystems.

Innovation / Entrepreneurship

The third group of papers on case research relating to industry emergence consists of a pair of papers looking at the innovation and entrepreneurship activities of business in emerging industries.

Fixson and Lee (2012) consider the process of knowledge creation within firms and how the effectiveness of strategies changes as the stage of the industry life cycle changes. The authors use the airbag industry in the USA between 1980 and 1995 as their case.

The authors explicitly identify their conceptualisation of knowledge creation as a search and recombination process. They use a typology of four types of knowledge exploration for this (after Rosenkopf and Neckar, 2001 quoted in Fixson and Lee, 2012);

- across organizational boundaries (external boundary spanning),
- across technological boundaries (internal boundary spanning),
- across neither boundary (local)
- across both boundaries simultaneously (radical)

The research uses available patent data to investigate its hypotheses and finds that the impact of the different types of knowledge search does indeed change as the industry emerges. Pre-takeoff knowledge exploration within the organisational boundary has more impact on the developed technology than search across the organisational boundary. As the industry sales take off, the greater impact comes from searches across the organisational boundary.

Gupta et al (2015) undertake a related study, looking at entrepreneurial activity during industry emergence. They take as their case the emergence of the personal computer industry.

The focus of the paper is on the theory elements of ‘discovery and creation’ as differing aspects that address the role of *agency* (the ability of individuals to make their own free choices) and *action* (making things happen) in entrepreneurship. According to the authors, these differing aspects are separated by very different philosophical perspectives; discovery assumes a realist ontology (the ‘thing’ is out there and just needs to be found); creation assumes a subjective ontology (the ‘thing’ is constructed internally to the individual).

The authors contend that these mechanisms are important as neo-classical models of the economy have ‘*a limited—if any—role for entrepreneurial behavior in the economy*’.

The methodology for researching this follows a highly novel approach; the authors review of a drama-documentary of the emergence of Silicon Valley (Pirates of Silicon Valley) and pick 5 scenes to investigate the actions of the portrayed entrepreneurs. The goal of the methodological approach is to '*interpret specific events in the broader context in which they occur, and to understand the larger picture by making sense of the individual events*'.

The findings are that;

- discovery and creation are interrelated
- during industry emergence the 2 approaches share 'bricolage' (making do with the resources at hand)
- ideological activism ('this' is the right thing to do) is important

The paper highlights the 'discovery & creation' processes are closely interrelated (regardless of philosophical differences) further identifying that the economy is driven by the spontaneous actions of enterprising individuals.

The final pair of papers relating to business and emergent issues looks at the way in which external actors impact upon the structure or operation of the individual business. The first paper, Prno and Slocombe (2014) is not looking at emerging industry per se, but is looking at an emergent phenomenon for an industry – that of a 'Social License to Operate' (SLO). The second piece of research (Mezias and Schloderer, 2016) is reported as a book chapter and is looking at 'isomorphism' - the tendency of organisations to have similar processes or structures to others in their industry.

In Prno and Slocombe (2014), the authors investigate the *emergence* (this author's emphasis) of a SLO in the mining industry and seek to generate a framework to support practitioners understand the SLO as it might apply to their case (e.g. a business or operation within a community).

The authors identify the need for the framework with the need to understand complex industry – community relations. A number of separate but linked contexts impact on these relations and are summarised as social, political and economic contexts.

The authors' research is identified as exploratory, and uses a qualitative approach of multiple cases to develop a systems based framework. This framework while 'grounded' builds from existing literature and the experience of a multi-year case study of the mining industry. This includes direct data collection via interview.

The authors explicitly state that systems approaches tend to avoid simple solutions to complex problems (echoing the HL Menken quote 'for every complex human problem, there is a solution that is neat, simple and wrong') but instead re-cast the problems as part of the overall system. Their approach to understanding draws on the systems constructs of complex-adaptive systems, resilience theories etc.

To add a level of validation, the resulting framework is tested against a specific case of a mining operation in the USA.

The authors find that the developed framework helped the validation case to identify a regional scale SLO in operation and clarified factors that led to local discontent about the mining operations. The authors highlight that the framework is not *predictive* – it is only a guide through the complexity of situation. The utility of the framework is it helps focus improvement efforts in community relations and enhances understanding of potential sources of conflict at both current and future operations.

The authors also highlight their research as demonstrating the difficulty in quickly assessing a system.

Mezias and Schloderer (2016) contribute a book chapter in which they investigate the elements of institutional theory and isomorphism as it relates to organisational forms during industry emergence (they use the term proto-industry phase). They build upon prior theory that has been usefully applied in a number of product and service industries (American health care, storage disc arrays, Singapore financial services, Dutch audit industry, American film industry) and which is summarised by Hsu and Hannan (2006, cited in Mezias and Scholerer 2016) as "the success of any social form depends on gaining the attention and endorsement of their evaluative audience."

The question of legitimisation of organisational forms is addressed via a simulation model covering mimetic / normative / coercive pressures. The authors' intent is to examine the role that institutional consensus has in the survival and success of new firms in new domains. The specific objective is to answer questions about the effects of institutional isomorphism on the formation of consensus about organisational forms during the proto-industry phase.

In describing the rational for simulating new industry, the authors cite the lack of knowledge about the early days of industry because of the difficulty of observing it. As the authors put it;

> '*Most attempts to start organisational clusters in new activity domains, like most attempts to start organisations, are likely doomed to failure.*'

As a result, there is a limitation to theories and findings based on observational data from emerged industries – they are a special case. The authors suggests that over-dependence on reviewing successful emerged industries can skew results and hence their decision to simulate industries to avoid this problem.

The findings from the simulation suggest that isomorphic pressures during the earliest stages of an industry can have beneficial impact on firm survival rates. The authors point to limitations in the modelling that assume no costs associated with these isomorphic pressures and that at least conceptually it is possible that these costs out-weigh the benefits.

Crucially, the authors indicate that:

> *'Policy-makers can improve the success of industry emergence through interventions aimed at accelerating consensus about new forms by enhancing institutional mechanisms'.*
> [Memetic, coercive, normative isomorphism]
>
> *'Similarly entrepreneurs may benefit from engagement in populations that help to create stronger isomorphic pressures, enhancing the speed with which audience members recognise and support new organisational forms.'*

2.6.4 Whole Industry

The remaining 8 papers looking at cases of industry emergence research the topic from the perspective of whole industries. They can be further split into groups of papers which consider system effects (3 off), policy (3 off), funding patterns (1 off) and supply network ecosystems (1 off).

System effects

The papers of Espinoza and Vredenbug (2010), Ford et al (2014) and Aspelund et al (2018) directly address questions of whole industry emergence.

Espinoza & Vredenburg (2010) explicitly identify the neglect of industry as the unit of analysis when studying sustainable development and position their paper as addressing the need for more research at the industry level.

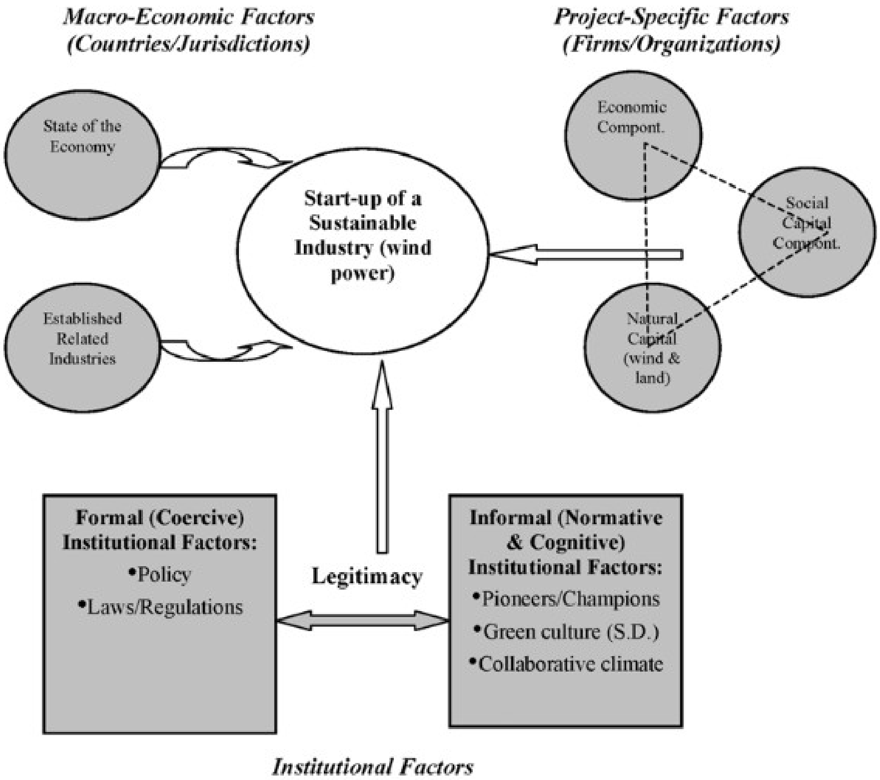
The paper itself is a multi-case study that analyses the development of wind power industry in a number of territories to help *'understand the influence of the different economic, institutional, and socio-cultural contexts over the start-up of sustainable industries'* (NB 'Sustainable' in this context relates to the technology under-pinning the industry rather than the ongoing existance of the industry). The cases are constructed through interview primarily with supporting secondary documentation and a review of literature. The individual cases are from different country contexts

(Denmark and Canada (Province of Alberta) as developed country cases; Costa Rica and Ecuador as less-developed country cases) chosen to be at least somewhat homogeneous in terms of size. The methodology is grounded theory.

The interviews are conducted within 3 stakeholder groupings of the industry; power utilities, the government and wind power organisations and community groups.

The authors were able to construct a model for the start-up of a sustainable (technology) industry:

Figure 2.11: A model explaining the start-up of a sustainable industry



Source: Espinoza and Vredenburg (2010)

The model helps explain that economic indicators are insufficient for explaining new industry development. A number of strategic resources are required – natural capital; social capital; legitimacy.

The authors consider that their work contributes to the domain of institutional theory in the way that developing legitimacy is seen as a driver for successful emergence. This ties in with the policy recommendations of Mezias and Schloderer (2016) discussed above.

Ford et al 2014 focus on the interaction of supply and demand in an emerging industry. The authors build upon the theories around co-evolutionary dynamics as they relate to supply and demand by researching the commercial inkjet printing industry in the Cambridge UK geographic area.

The interaction of supply and demand is highlighted as a significant aspect to industry emergence as the existing theory on new technological trajectories (going back as far as Schumpeter (1928) cited in Ford et al 2014) is seen to be as a result of radical innovations which in turn are identified as supply-side driven. As industry progresses the innovations become more incremental and demand-side driven.

The case is developed through interview with 13 professionals involved in the industry in commercial inkjet or related firms. The industry was chosen as the technologies originated in Cambridge and Cambridge-based firms remain at the forefront of developments; a second reason is that the industry continues to evolve with new printing technologies being introduced.

The interviews themselves were conducted with a semi-structured visual mapping technique developed from technology roadmapping. The timeline provides the horizontal axis and the vertical axis is split into initial technology; application; market categories. Events and activities were explored on this canvas.

The research uncovers 2 broad technological trajectories in the different technologies with one (continuous inkjet) reaching maturity and a second (droplet on demand) still rapidly evolving in terms of market areas to address.

The paper shows that there are systemic interactions between supply and demand in this emerging industry – there is feedback between the two sides (supply affects demand, demand affects supply) and ‘asynchronicities’ in the development – changes and effects occur at different times and can’t easily be reconciled as cause and effect.

Feedback elements include the need to develop specialised inks to address markets, but ink developers needing to see significant markets to develop such inks. A second feedback was customers’ prior (bad) experience of new print technologies and so a reluctance to adopt the inkjet technologies on offer. This in turn compounds the asynchronicity between supply and demand.

The paper concludes with the observation that market activity comprises a number of intersecting ecosystems including the industrial ecosystem the new technology seeks to supplant.

In the final paper looking at system effects (Aspelund et al 2018), the authors investigate the development of the Norwegian electronics industry. They start by stating the obviousness of it being desirable to have '*internationally competitive knowledge-based or technology-intensive industries*'. They contrast this self-evident goal with the lack of consensus on how to create and nurture such industries with many different recipes being offered by different schools of thought and hence the need to research the emergence of industries in a more grounded way.

The selection of the Norwegian electronics industry supports the 'creation and nurture' focus as the industry itself had few preconditions for emergence in Norway e.g. pre-existing technological capability, favourable structural conditions. In order to succeed it had to reach global markets from the start ('born global').

The authors follow a qualitative, historical, multi-level case study methodology where the interviews with (9) entrepreneurs (6 in-depth and 3 focussed) is supplemented by 40 years of historical data. The case is presented chronologically and is discussed from both a structural economic perspective and an entrepreneurship perspective.

The authors find that the industry was significantly influenced by a handful of entrepreneurs with particular capabilities (ambition, technical skills, international vision) rather than by favourable structural conditions. The state had a pivotal role as an entrepreneurial agent building knowledge platforms. 'Coopetition' between firms and close collaboration between industry / university were important at a number of points in time (in contrast to continuously).

They conclude that there are few structural reasons for successful emergence of the industry in Norway; and that the success is due to a knowledge platform created by the state that is then turned into robust international business through the actions of a few ambitious and extremely technically competent individuals (entrepreneurs) with global vision.

They recommend that the birth and development pattern of industries are better described by shifting focus from a structural view of comparative advantage and path dependency, toward a more behavioural view based on international entrepreneurship and path creation. They also recognise that both perspectives are necessary as state action is required to build the 'knowledge platform' the industry can spin-off from.

Policy Impact

The policy related papers start with the work of Klitkou and Godoe (2013) looking at the emergence of the Norwegian Solar Photovoltaic (SolarPV) manufacturing industry from the perspective of the Triple Helix (where the three elements are Industry / Government / Academia).

The Norwegian PV industry is chosen by the authors as it is a globally relevant industry which supplies 10% – 20% of the market for specific elements of the global PV supply chain such as silicon wafers.

The authors explore the triple helix theory (including agency of the participants) and they state that; "*Cultural evolution...is driven by individuals and groups who make conscious decisions as well as the appearance of unintended consequences*".

The paper critiques innovation research as suggesting that radical innovations emerge because of chance and other random or haphazard factors. It considers this an unsatisfactory explanation because numerous high-tech radical innovations are outcomes of technological agency and associated strategic research and development. Examples cited are the development of Internet (Mowery and Simcoe, 2002), the mobile communication system GSM (Godoe, 2000), NASA's success in "putting a man on the moon".

The success of SolarPV in Norway is seen as an outcome of Norway's grand strategies. The authors assert that the grand strategies have been an important mechanism that has allowed Norway to avoid the often cited economic 'curse' that has afflicted nations that have found themselves in possession of valuable natural resources (examples of the 'cursed' nations cited are Venezuela, Romania, Nigeria).

The research investigates the interactions between existing companies, the emergence of new PV companies, public R&D funding programmes and research organisations—and policy contexts that fostered the emergence of this new industry. The paper is based on a combination of qualitative (interviews and document analysis) and quantitative methods (project data and RD&D budget data).

The authors identify the following features of Norwegian SolarPV emergence;

- diversification of metallurgy industries into PV
- high R&D and innovation activity
- inexpensive hydroelectric power
- private and public investors
- the availability of an educated work force
- local government support as well as national and international R&D funding programmes
- connections to international technology suppliers

- strong international demand for silicon wafers

The authors find that ‘technological agency’ (purposive technological action and decisions) can counteract market-based approaches which might make an industry unfavourable (e.g. comparative disadvantage, lack of structural pre-conditions etc.).

The authors acknowledge that external factors played a part e.g. a surge in global demand helped at right time. Within the industry it is identified that a crucial element was that a few scientists anticipated the opportunity and focussed on capturing benefits from the opportunity.

The industry, while not benefiting from broader structural benefits, nonetheless needed the existing knowledge base within academia and research bodies to make it happen. The final element of the triple helix, government, played its part by reacting quickly to support the industry e.g. through funding.

A paper by Ruan et al (2014) looks at a far more direct form of government involvement in industry emergence from the case of the emerging e-bike industry in China. The authors cite the nature of innovation in emerging economies (as opposed to emerging industry) as of interest due to the particular needs of the mass-market for robust, basic products at ultra-low prices. Further, they identify that research on the role of government policy in emerging economies has been focussed on developed and capitalist economies.

The paper cites a model for government innovation policies (from Dolsfma & Seo 2013, cited in Ruan et al 2013) based on a 2x2 matrix with the dimensions of ‘network effect on market’ (high / low) and ‘technology’ (discrete / cumulative). This is shown in figure 2.12 below.

Figure 2.12: Model of government innovation policies

	Discrete technology	Cumulative technology
Low Network effect on Market	***Romanticism*** Funding and tax credits for R&D. Supporting universities and research centres. Assisting companies to commercialize innovative technology. Innovation vouchers. Stimulate innovative entrepreneurship	***Standing on the shoulders of giants*** Promote regional clustering. Encouraging technology upgrades through subsidies and tax credits. Procurement policies. Innovation brokerage.
High network effect on market	**Schumpeter mark I** Easy access to intellectual property by third parties. Promoting harmonized standards or requiring compatibility among technologies.	**Schumpeter mark II** Activating antitrust law to prevent lock-in. Deregulate industries. Liberalize markets. Standard setting/ enforcing. Flexible IPR regime.

A ‘discrete’ technology is one where the innovation is wholly new and unrelated to what has come before. ‘Cumulative’ technology is one where the innovation depends on the combination of pre-existing ideas. The ‘network’ effect of a technology on a market relates to the impact increasing penetration to the market the technology has – the telephone system is an example. The phone has no use until you have someone to phone with it.

The value of this model is that it takes the characteristics of an innovation into account when considering policies.

The paper considers what makes a technology ‘disruptive’ and concludes that the eBike is disruptive in part because it does not sustain the existing internal combustion engined (ICE) scooter industry. (By way on contrast, a new transmission technology would not be disruptive as it can be adopted by the ICE industry).

The research was conducted by interview with eBike manufacturers and their suppliers and also industry association leaders but not government officials. Such secondary published data as was available was included, but the authors stated there was only a limited amount available and that they relied on archival research to address this.

The interviews focussed on the industrialist knowledge of government policies affecting their industry, and for the industry association leaders the focus was on their views on the overall industry and on central and regional government policy.

The authors sought to identify;

- how did the government initially participate in the development of the innovation and the emergence of the industry?
- how did the National Standard (GB17761-1999) and the relevant road transportation laws influence the industry?
- how did the government promote and regulate the industry after its exponential growth?
- how are the local governments' policies different from the central government's?

The following policy streams are identified as government's contribution to building the industry;

- Central government's initiation – the naming of e-vehicles as an important technology in the ninth 5-year plan
- The National Standard and Road Transportation law – this identified what a eBike is, and had a significant loophole that allowed e-scooters to be classified as an eBike
- Regulation and continuous promotion – closing the above loophole in response to escalating eBike death toll
- Local government policies – this determined the extent to which central government policies impacted on the desirability of eBikes e.g. by considering how the ban on motorbikes in a city was implemented.

Overall the authors find that the successful development of E-bikes can be attributed to well-matched policies according to the characteristics of the innovation.

The final piece of research looking at whole industry impacts of policies is the work of Edman and Ahmadjian (2017). In their chapter in 'Emergence' they look at the effect of creating 'empty categories' on the emergence of new industries.

The authors explain that 'empty categories' are industries which exist prior to the existence of producers and consumers (e.g. in terms of government description). Their review of literature identifies that the emergence of new industries depends not only on new technologies, resources and markets but also on the creation of common meanings and identities related to that industry through the construction of categories.

The authors describe a process of 'categorisation' that emerges as an industry develops between consumers and producers in contrast to the 'empty category' - created by external actors. Of particular interest are the implications for the ‘identity of entrants, their products and long-term viability’.

To research the impact of ‘empty categories’ the authors look to the case of local beer (‘ji-biru’) in Japan. This category was defined by the the authorities as an equivalent to a prevalent category of sake – local sake (‘ji-zake’). It was established during the deregulation of Japanese micro-brewing in the 1990’s and the authors follow this industry trajectory through to 2007.

The research follows case methodology and the data is collected through primary interview and uses archival records and industry data to triangulate the data set. The qualitative data was augmented by quantitative data on firm entry and exit rates and by the identity and themes of the various actors in the industry.

The authors find that the establishment of an empty category ‘ji-biru’ helped shape the Japanese micro-brewery industry following de-regulation. They suggest that the category accelerated market entry as there were few barriers to entry, but at the same time the lack of a consensus amongst entrants about what ‘ji-biru’ really was led to fast stagnation (within 10 years) and a large number of firms exiting the category. This is seen to be due to the external actors who broadly established the category losing interest and internal producers lacking cohesion. The micro-brewery industry was then ‘rescued’ by the creation of an alternate category of ‘craft beer’.

The authors conclude that while such ‘empty categories’ are helpful in accelerating the growth of an industry (by providing legitimacy) they also impede (necessary?) evolutionary forces by inhibiting shared understanding of what constitutes a category member.

The final 2 papers looking at emerging industries with the industry as the unit of analysis look at distinct aspects. The first (Xia and Minshall 2013) considers investment patterns in an emerging industry and the second (Srai et al 2017) considers the development of supply networks in developing markets.

Investment patterns

Xia and Minshall contribute a book chapter (Xia and Minshall, 2013) that looks at the whole industry level to investigate investment in new technology. The authors start by considering that while much research has been directed at understanding the roles of differing types of investment in the development of a new technology, there has been little research on industry wide effects. They seek to address this by looking at the patterns of public and private investment in new technologies and the role of government in support of financing the emergence of new industries. Their focus is on the ‘valley of death’ stage between prototypes and commercial offerings where both technology and market uncertainty is high.

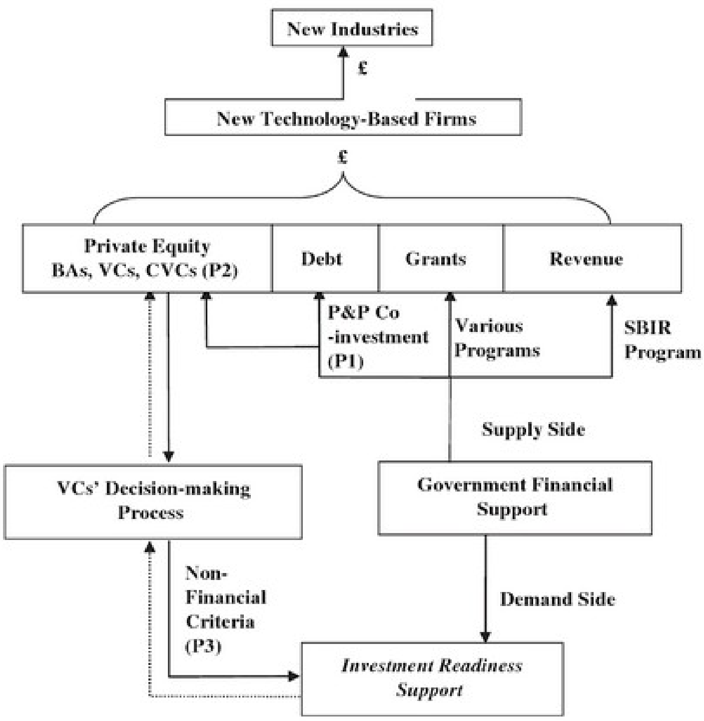
The research is conducted on historical data (in the form of government and industry reports and publications) on technology investment forms (Grants, equity, Debt, Revenue). The authors review existing research on these forms prior to considering the public (sector) support for financing of new firms in emerging industries.

From these strands the authors construct a framework (figure N below) which seeks to aid the understanding of financing for new firms in emerging industries.

They have 3 propositions:

- Few investors in early-stage technology firms concentrate on the demand side; seeking instead non-financial criteria
- On the supply side, government financial support and programs, public/ / private co-investment can stimulate levels of grant, debt and private equity investment
- Corporate venture capital (CVC) may provide an alternate source of investment where the corporate company seeks to identify and exploit synergies rather than relying on pure financial considerations

Figure 2.13: Conceptual framework for the funding of new firms in emerging industries



The authors conclude that there are a broad range of actors who currently shape the financing picture of new science and technology firms; business angels (who fund seed level activity), university commercialisation (again small scale investment), venture capitalists (who look for more assured returns from larger scale investment), banks and government programmes (including private / public co-investment). They consider that CVCs may be an important future source of finance. They identify that more detailed work is required to operationalise their framework, perhaps generating more specific forms for different types of industry.

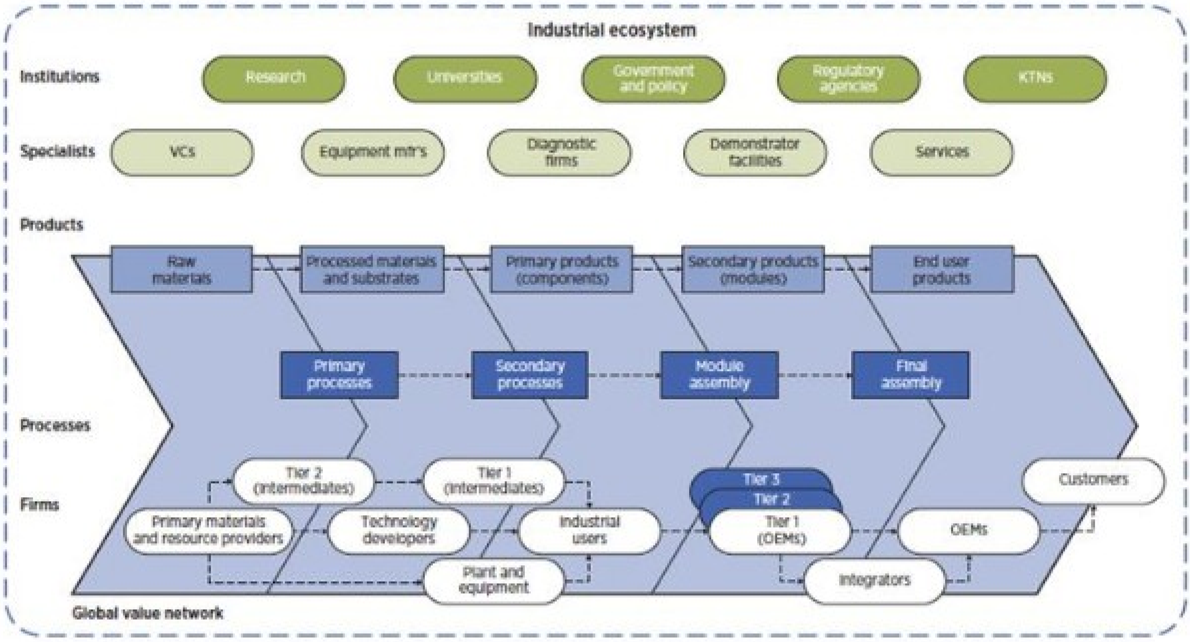
Supply Chain Networks

The paper by Srai et al (2016) looks at the phenomenon of redistributed manufacturing systems within the context of supply networks of emerging industry. The structure, operation and dynamics of reconfiguration are a particular focus. The authors identify that the redistribution of manufacturing is happening as a consequence of advances in (manufacturing) processes and in information technologies. These factors change the viable scale for production and the physical and informational characteristics of products. This further leads to, or is caused by, the emergence of new specialised companies in research, production and service roles.

The background to the research is that prior research on the structure and performance of industrial systems and clusters has focussed on mature industry. The authors identify that a series of new industrial systems are emerging that may provide insights into structure, dynamics and the reconfiguration of networks for redistributed manufacture.

The research is conducted across 6 industrial systems and uses an industry system mapping methodology developed by one of the authors (Srai 2016, cited in Srai et al 2017) to facilitate cross-case comparisons. The research focus is on one key perspective – how emerging industry supply networks address and respond to the opportunities and challenges of (re)distributed manufacturing models. The generic industrial systems mapping framework is shown in figure 2.14 below.

Figure 2.14: Generic industrial systems mapping framework (source Srai 2016, cited in Srai et al 2017).



The mapping technique captures those environmental features of the industry systems that are influenced by dynamic factors (such as market, product, production system, technology, policy and resources) and providing the platform for cross-case analysis. The methodology is qualitative analysis of cross-cases. The analysis relies on using pre-configured codes / themes.

The participants in each case in the study include:

- Institutional players and secondary stakeholders
- Sector specialists and primary stakeholders
- Value chain actors and activities
- Supply network archetypes that form the supply chain
- Firms within the supply network archetypes

The research brings forward the importance of the industrial system that ‘connects’ the technology developments to final products, supplementing the previously well-articulated linkage between technology platforms and final product innovations. The conceptual framework developed implies that the industrial system has a change path that is must bridge from ‘technology 1’ to ‘technology 2’ and from ‘product 1’ to ‘product 2’.

The authors are able to identify the following generic aspects to supply networks in emerging industries:

1. Industry boundaries are blurring – it is harder to identify firms with a single industry
2. Managing uncertainty is a critical requirement in select parts of the supply network
3. Alternate forms of supply network can be observed coexisting within one product area and sector
4. Platform technologies supporting multiple product categories are often disconnected from end-user markets
5. Importance of particular types of value chain actors to provide network integration and supply / demand uncertainty management is observed. The actors include System integrators, Technology developers, Resource capturers, Asset diversifiers and material/information Consolidators

2.6.5 Closing remarks on case research

The existing research on case study of emerging industries comes from a large range of perspectives and theoretical underpinnings. There is no clear trend of a move from an intellectual domain stance (e.g. evolutionary economics or business strategy) towards a whole industry approach despite the call for research taking the industry as a unit of analysis (see Espinoza & Vredenburg, 2010) and individual elements that provide some insight into this research's goal of supporting emergence of viable new industries come from many domains.

This can be interpreted as indicating an emerging area of study where many alternative approaches are being tried. This view is supported by number of the authors identifying the need for further research on emerging industries (particularly amongst more recent papers), either to expand their own theoretic constructs or to address the limited scope of descriptive cases of emerging industries.

It is also a feature that all of the papers are describing research that happened after the industry in focus had emerged. Where this fact is discussed, the authors point to the difficulties of identifying potentially emerging industries and the complexity in covering the aspects required by theory. Tanner (2014) makes explicit reference to the need for contemporaneous research to get to the 'essence' of how and why industries emerge. Mezias & Schloderer (2016) take another tack to bypass the issue entirely. Their research is conducted by modelling generic emerging industry to determine the impacts of (in this case the impact of isomorphism on emerging industry). The data from interviews must be impacted by the effects of hindsight on individuals memories (e.g. lucky outcomes become skilfully managed actions).

It can be taken from this over-arching view that there is a need for more grounded investigation of cases of emerging industry, during the period of emergence. This will be explored more in the summary section of this literature as specific research gaps are explored.

2.7 Summary

This chapter reviewed the literature that currently exists that may give insights to the original question 'How do we create a viable new industry for offshore wind power'. The literature does identify a number of single factors and drivers that support the emergence of new industries and provides some indicators that suggest whether the industry has reached the emergence point. These drivers and indicators are summarised in table 2.7 below.

Table 2.7: Drivers and Indicators for emerging industry.

Drivers during emergence	Indicators of emergence
Technological discontinuity Market discontinuity Entrepreneurial action Legitimacy Institutional isomorphism Risk reduction – through policy Risk reduction – through technological support 'Local' technological antecedents	Dominant designs Accelerated sales growth Firm shake-out Move from product to process innovation

The existing research has a number of limitations when it comes to addressing the original question regarding how to fruitfully engage with a potential new industry to support its emergence in a viable form.

A fundamental limitation is that all the case research to date has been after the fact – the industries researched have already successfully emerged. This limitation is acknowledged by Tanner (2016), and addressing it is a key objective for this research.

The literature also points to the limitation (see Peltoniemi 2011) that the research has been focussed on mass-manufacture product industries rather than complex product system (CoPS) industries. While there are cases looking at the emergence of industries that can be seen as CoPS (see Vasi 2009, Carlos 2018), the nature and impact of this distinction of industry types is not addressed. This research provides the opportunity to consider theory as it applies in CoPS situation.

Both the theory building and the empirical research have focussed on single factors and indicators in the individual pieces of work. While this helps build knowledge around these single factors there is a lack of insight into the interaction of factors e.g. how do entrepreneurial action and institutional isomorphism combine where risk reduction through policy is weak? When one considers the potential number of combinations of factors, and the relative infrequency of new industry emergence, one can see that the reductionist approach has limited scope to provide an answer to the core question of aiding the emergence of viable industries.

The existing research is constrained by unhelpful definitions of industry. In the main, researchers side step the issue by looking at industries post-emergence where the constituent organisations can be selected e.g. by looking at OEMs and their supply chains. The alternative approach used is to select based on SIC codes. The limitations of such approaches is addressed in full above, but particular note is given to the difficulty in applying such selections before the industry has emerged – which organisations should be included?

It is also notable that the idea of using the industry as the ‘unit of analysis’ is just emerging in the literature. A number of the studies across diverse domains identify the importance of this approach (see Ford 2014, Potstada 2016, Edman & Ahmadijan 2017).

The economics and business literature does not directly address viability of emerging industries – only the very recent book chapter (Edman 2017) paper makes any commentary on viability, and this is to consider the danger of building a new ‘category’ (taken here as an industry sector) without building a consensus on what the norms for participants should be. The work of Klitkou (2013) highlights an emerged industry that lacks the capacity to respond to a changing environment (lacks ‘viability’) and industry activity moves elsewhere globally during the financial crisis.

The Systems Thinking literature does address the question of address viability in general terms (see Beer’s VSM and Miller’s LST) although only the VSM has been used in industry settings – and not to consider emergence.

There are then a number of gaps in the literature that need to be addressed to begin to answer the original question.

2.7.1 The need to study an emerging industry during emergence

The case research literature shows there is still a need to address a lack of knowledge in the emergence of new industries. Recent studies (post 2013) highlight that existing studies look at the case *after* emergence. This is done due to the difficulties in identifying an industry that *will* emerge thereby avoiding the risk of investigating a null case.

The result is a significant bias in case selection that has the potential to impact on the results of theory. There is, then, a need for investigation of emergent industries during their emergence stage. This research should be substantively 'grounded' – what is observed is more important than the theoretical frameworks it can be fitted to – and exploratory in nature.

There is a genuine risk that the industry will not emerge, but even a carefully recorded and understood failure to emerge will represent a valuable case.

2.7.2 The need to understand if a CoPS industry has the same drivers and indicators of emergence

The review by Peltoniemi (2011) highlights that CoPS type industries (amongst others) are not represented by the existing literature. There are clear structural differences between a typical product / mass manufacture industry and complex product system industries that cast doubt on the theoretical frameworks for emergence e.g. large numbers of firms entering and exiting industry, product innovation before process innovation.

Offshore Wind Power therefore presents an important opportunity to observe a potentially emergent industry during its emergence and to consider how the existing drivers and indicators of emergence fit a CoPS industry.

2.7.3 The need to consider how factors interact

The literature reviewed demonstrates a progression from considering processes in individual firms (entrepreneurial activity, spin-outs, diversification) and the performance of industries as a whole (via metrics analysed along SIC code divisions) towards a greater focus on the dynamics of networks of firms and other organisations. This work is principally in the domains of evolutionary economic geography and business ecosystems (whether supply networks or technologically proximate institutions). The later papers on industry emergence have begun to look at the wider context within which firms, supply chains and/or industrial ecosystems operate to build understanding on the emergence of industry.

A few papers (e.g. Shi 2013, Prno and Slocombe 2014, Ford 2014) have explicitly introduced systems concepts and reviewed activity in systems terms, although as identified above, none of the business and economics literature addresses the long term viability of emergent industries (although a few – notably Edman and Ahmadjian 2017 – identify that early interventions can have a negative impact on viability).

Systems Thinking cautions against looking for simple causal links in complex systems – cause and effect can be bound together (e.g. in Ford 2014 where supply and demand influence each other) and can act at some distance in geography and time.

This suggests that an approach to an emerging industry that explicitly looks at how previously researched factors interact may be a fruitful way to build upon the existing work potentially providing new insights into how individuals and institutions can interact with the industry to support its emergence in a viable form.

3. Methodology & Research Design

Research design is defined by Yin, 2009 as the way in which the research data are logically connected to a study's research questions and through analysis to its conclusions.

This chapter identifies the research design, and it's related methodology, chosen to address the previously surfaced research problem. The selection is explained in the context of alternative approaches and its use is justified in comparison to the potential alternatives through reasoned exclusion.

The chapter begins with a setting out of the aims and purpose of this research. This is followed by an exposition of the objectives and research questions that are used to give a frame to the investigation carried out.

The research paradigm is then presented and discussed in relation to its component elements (ontology, epistemology, axiology and methodology). The basis for this research is then decided upon and the rationale explained.

The chapter completes with an exploration of the measures around research formation, data collection and analysis that ensure the research is conducted in a rigorous manner.

3.1 Aim & Purpose

The preceding chapters have established the need to understand how the emergence of new industries can be supported in ways that maximise the benefit to the economy and potentially wider society. The review of literature identifies that although there is an existing body of research that tackles individual aspects of the emergence of industries in some detail, both from the viewpoint of individual firms' approach to new opportunities and of industries in general developing over time, there are important gaps in the knowledge base. The literature itself recognises the limitations that come from the use of post-hoc cases and that the theory base is built upon review of mass-manufacture industries only. The review also shows that limitations arise from the focus of research on single factors rather than whole industry effects.

The limitations of previous research arise in part from the lack of a definition for industry that is practical during the pre-emergence stage. The literature review shows that Systems Thinking approaches can help address the issues of industry definition and interaction of multiple factors. The Systems literature also introduces the principle of 'viability' of an emerged industry.

Hence the overall aim of this research is:

> "… to understand industry emergence as it relates to Offshore Wind Power to better support emergence of future industries."

The research will broaden existing research by observing a complex product system industry to see how the drivers and indicators of emergence previously identified in mass manufacture industries relate to offshore wind power.

The research also aims to extend knowledge by observing the industry during its emergence offering a richer understanding of how the phenomenon occurs potentially leading to a framework for interaction to support the emergence of future industries.

3.2 Objectives

To achieve the over-arching goals the research has been split into a series of more specific goals.

Understand how the OWP industry's emergence relates to existing theory

As will be explored in the literature review, the existing knowledge on the drivers and indicators of emerging industries is based on the post-hoc analysis of mass-manufacture industries. The emergence of Complex Product Systems industries has not been investigated, but comparisons between other aspects of mass manufacture and complex product system industries (e.g. resource capabilities) suggest that differences can be anticipated.

Understand interaction of factors during emergence

Prior studies on the emergence of industries have focussed on the impact of individual drivers across a range of industries. Observation of an industry during its emergence offers the opportunity to understand whether and / or how the multiple drivers of emergence interact to impact on the emergence of the industry.

Assessing indicators of emergence and viability during emergence

The identification of emerged industries is a trivial matter once the industry is established. This research will look at how the state of emergence can be assessed during the industry's emergence –

whether existing indicators provide clear information, or whether alternate indicators are required. Of particular interest is whether the industry's ongoing future (viability) can be assessed.

3.3 Research questions

3.3.1 RQ1 Does OWP follow the pattern of emergence identified in the literature?

This question investigates the relevance of existing theory (built on mass manufacturing industries) to a complex product system industry. The existing theory can be tested via the applicability of the drivers for emergence and the indicators of emergence in this case i.e.;

- Are the drivers for emergence identified in the literature apparent in the emergence of Offshore Wind Power as an industry?
- Are these drivers for emergence observed to function in the same way in the Offshore Wind Power industry?
- Are any others drivers for emergence observed in the Offshore Wind Power industry?
- Are the indicators of emergence identified in the literature apparent in the Offshore Wind Power industry?
- What other indicators of emergence are observed in the industry?

3.3.2 RQ2 What can be learned from the observation of an industry during its emergence?

Prior investigations of emerging industries have been undertaken after the industries' emergence, based on the recorded data from the emergence stage. The observation of an industry during its emergence offers the opportunity to build a richer picture of the phenomenon – e.g. from the reaction of individuals and organisations to policy to the way individual drivers for emergence interact. Systems Thinking approaches will address questions of;

- How do forces / drivers for emergence interact in the industry activities?
- How do the ways supporting agencies interact with the industry impact on emergence?
- How is the ongoing viability of the industry considered during emergence?

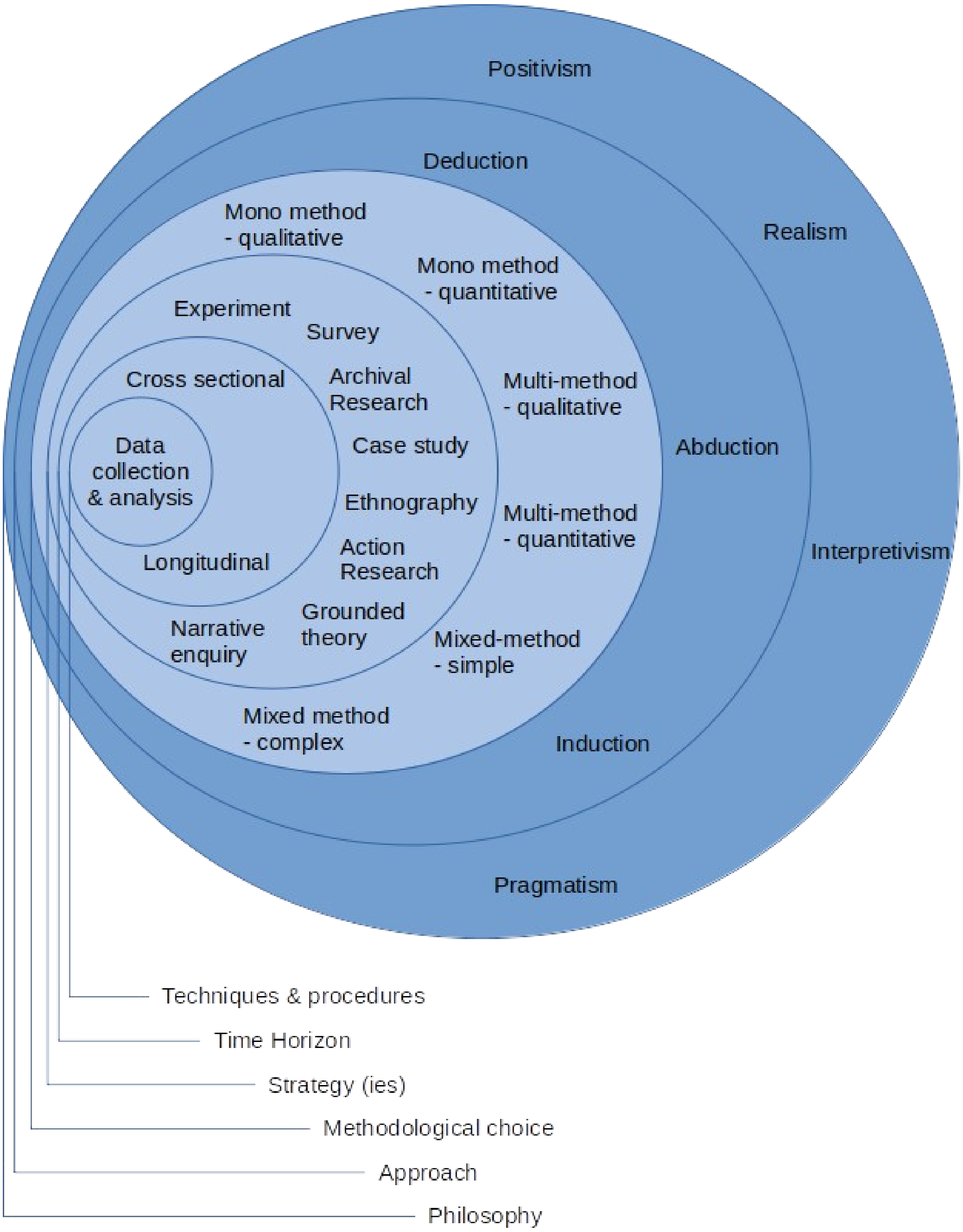
3.4 Positioning the research

To undertake research in a rigorous manner, the researcher must first address issues of the nature of the knowledge sought and make explicit choices about how the enquiry should be structured and carried out. Underpinning this choice is the researcher's own beliefs and understanding of the nature of the world around them and the choice may not be entirely conscious as these beliefs will be built up from values, perceptions, experiences and hence beliefs that have built up over the course of the researchers life. For a more mature researcher these beliefs can be quite extensive and this world view will impact on the research approach through their approach to reasoning.

It is also the case that the nature of the phenomena under study will also impact decisions on the structure of the research – a social scientist would not ask a proton how it felt about its make up, nor (one hopes) would a physicist smash people together to see how they got on. The research path must be suitable for the understanding that is sought.

The initial stage of research design is to consider how the research problem fits within a framework of philosophical and theoretical perspectives (Cresswell, 1997) and through this understanding ensure the approach proposed can meet the research objectives. Figure 3.1 below sets out how the different types of study, modes of enquiry and philosophical stances of the researcher can be considered as a series of nested layers (after the 'research onion' - Saunders et al, 2012).

Figure 3.1: Research Onion



The layers can be understood as follows:

As the researcher considers the research problem they will need to address to a number of decision points where the choices made constrain the options available in more detailed design. These decision points can be considered to flow from the outer layer of the 'onion' to the core as follows:

- Philosophical stance: this covers the ontology – what is the underlying nature of the world being investigated – and the epistemology – how researcher relates to their topic of study

- Methodological stance: this covers the methodological choices and the strategies that will be employed in the research – i.e. how can the topic be investigated
- Time horizon: what is the impact of time on the research
- Techniques: what are appropriate procedures and tools to do the investigation

The collected decisions made defines the 'Research Paradigm' for the study. It is this paradigm which is the foundation for building robust and rigorous research. It follows that these decisions cannot be made lightly and the researcher must understand the context and implications of choice.

The next section examines each element of the research paradigm and considers the options that researcher must choose between.

3.5 The Research Paradigm

The 'Research Paradigm' is the framework within which the researcher conducts their research. Any researcher will come to the work with a pre-existing set of beliefs and assumptions that create a world-view that guides the researcher's actions. This implicit framework may, or may not be relevant to the phenomena to be studied. These assumptions must therefore be explored and understood by the researcher and the pertinence to the phenomena being studied examined.

The underlying assumptions can be considered as;

- the ontological issue: assumptions related to the nature of reality
- the epistemological issue: how does the researcher know what they know
- the axiological issue: the role values play in the inquiry
- the methodological issue: the process of research and how it fits with the previous issues

The following sections investigate these issues and how they build towards an appropriate research paradigm.

3.5.1 Ontology

As stated above, the ontological issue relates to the nature of reality, *as seen by the researcher.* Easterby-Smith et al (2008) identify that a failure to consider these assumptions as they relate to the researcher's investigation can have a serious impact on the quality of the research. From a more supportive view, consideration of the ontological issue can benefit researchers by;

- helping to clarify research designs, what kinds of evidence, how it may be gathered

- helping select between research approaches with the best chance of success
- helping identify (or create) research designs beyond the researcher's prior experience

The central concern for the researcher to consider is how is this reality constructed. This is not solely related to the researcher themselves but by all the agents in the research situation – the researcher, any individuals involved in the study and the final audience for the research outcomes.

There are frequently described two broad ontological positions;

- Objectivism (associated with quantitative studies)
- Subjectivism (associated with qualitative studies)

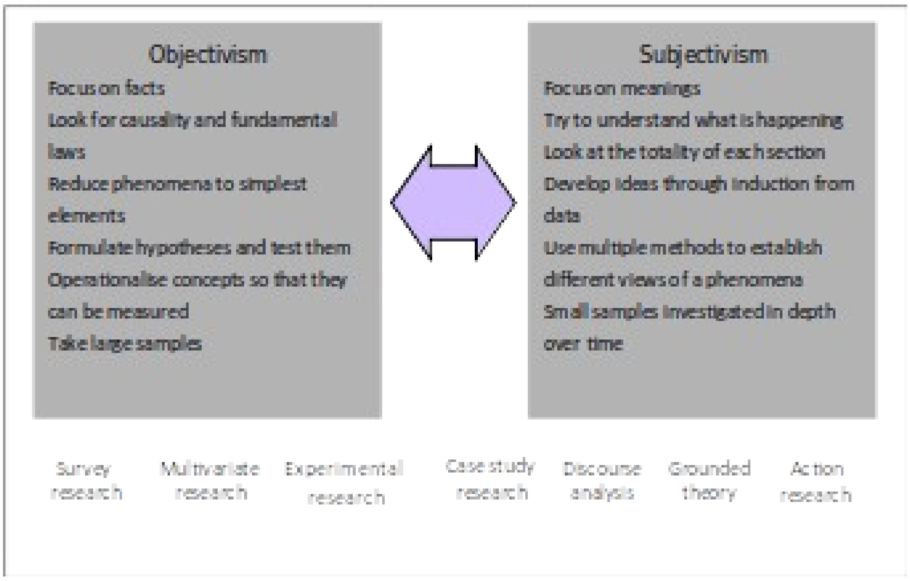
Objectivism as an ontological stance asserts that phenomena and their meaning have an existence that is independent of the involved actors (Bryman, 2008). It is a position most associated with physical sciences where hard facts can measured, elements can be reduced to component parts and the interplay of inputs and outputs can be assigned to causality. The reality observed is 'objective', nothing comes from the researcher/observer and nothing is changed by a different researcher doing the observation.

Subjectivism sits as the antithesis of this viewpoint. In this world-view there are elements and phenomena that can be discussed and described but not objectively measured. Their existence cannot be said to be scientifically proven, none the less they exist. The foundations of a subjective reality is that its 'truth' depends on the observer who establishes it. By definition, its 'facts' are *created* by the person observing them.

Subjectivism is most strongly associated with social science and situations where the research aims to understand peoples' perceptions and interpretations of the study phenomena.

Figure 3.2 below attempts to summarise this dichotomy and show how research methods range between the two ontological stances.

Figure 3.2: Ontological dimension



(summarised from Beech, 2005)

3.5.2 Epistemology

Easterby-Smith et al (2008) describe epistemology as a '*general set of assumptions about the best way to inquire into the nature of the world*'. These assumptions are seen to coincide with the particular ontological stance of the researcher – the consequences of them not doing so is to reduce the quality and validity of the research.

However it must be recognised that the epistemological choice is not binary. The use of the polar extremes of Positivism and Social Constructionism in epistemology to highlight the type of choices made by the researcher can give this impression. Indeed writers such as Creswell (2009) and Easterby-Smith et al (2008) describe the elevation of the positions into stereotypes. This is seen to have the impact that contructionalists reject the application of natural science approaches (experimentation, measurement etc.) for understanding social constructs and positivists consider constructionalists research as unreliable and not credible due to this lack. Neither stance recognises that the positions are poles of a spectrum. The researcher, the subject and the research approach must 'fit together' to assure the validity of the knowledge being sought (or constructed).

To begin to consider where the research sits it is useful to understand these stereotypical positions and these are described below. Table 3.1 below sets out a summary comparison.

Positivism

The positivist epistemological stance makes the case for the application of the approach and methods of physical sciences to the study of any aspect of reality. Beyond this general description it becomes difficult to set down with precision as it is used differently by different authors as outlined by Bryman (2008). Some examples of this disparity are shown in Easterby-Smith et al (2008) who propose that the positivist paradigm sees the social world to exist externally to the researcher and that therefore it must be possible to measure its properties objectively. To infer the properties subjectively through sensation, reflection and intuition is to add error and bias into the study.

Krauss (2005) identifies the positivist stance as determining that knowledge of anything that is beyond what we can observe and measure is impossible. This is extended to say that if it cannot be measured then it does not exist.

The exposition of positivism from Collis & Hussey (2013) bridges these two positions. For them reality in a positivist paradigm is assumed to be objective and singular outside the perception of the observer. Facts exist independently of the observer and of any theories held. The truth is therefore definite and ascertainable (through measurement).

Social Constructionism

This approach has been considered as the ‘new paradigm’ for research and has been developed from the middle of the twentieth century in large part as a reaction to positivism and the application of that epistemological stance to social science. The paradigm shift comes from understanding that not all ‘reality’ can be measured objectively. In contrast to the external and objective nature of reality, it is recognised that what is real is ‘socially constructed’ and given meaning by individuals and groups (Easterby-Smith et al, 2008). This stance flows naturally from the subjective ontology.

As a doctrine, Social Constructionism sets the task of the researcher to be the appreciation of the different constructions and meanings that people place upon their individual and shared experience. It is not to gather ‘facts’ and measure the frequency of specific patterns. The focus of research is therefore on what people are thinking and feeling – individually and collectively – and on their communication with each other. The researcher should consider any quantification to be limited in nature (Krauss, 2005).

The above 2 epistemological stances can be summarised and contrasted as shown in table 3.1 below.

Table 3.1: Contrasting epistemologies

	Positivism	**Social Constructionism**
The observer ...	must be independent	is part of what is being observed
Human interests ...	should be irrelevant	are the main drivers of science
Explanations ...	must demonstrate causality	aim to increase general understanding of the situation
Research Progresses through ...	hypotheses and deductions	gathering rich data from which ideas are induced
Concepts ...	need to be operationalized so that they can be measured	should incorporate stakeholder perspectives
Unit of analysis ...	should be reduced to simplest terms	may include the complexity of ‘whole’ situations
Generalization through ...	statistical probability	theoretical abstraction
Sampling requires ...	large numbers selected randomly	small numbers of cases chosen for specific reasons

Realism

As has been stated and shown, the positivist and interpretivist stances cannot easily be reconciled and yet researchers find it uncomfortable to sit fully in either camp as there are elements of each that they agree with. Newman & Benz (1998) tell us that it is important to understand the epistemological stance to be a spectrum with varying levels of positivism and interpretivism.

Realism provides a middle ground in this spectrum. It leans to the positivist stance in that it recognises an external reality in the natural order, and that understanding and changing the social world requires that we identify underlying structures that generate the social worlds events and discourses. Bryman (2008) identifies that realism holds that both natural and social sciences should apply common approaches to the collection of data and their analysis and explanation.

This centre ground can be further refined into empirical realism and critical realism (Creswell, 2007). Empirical realism 'is the doctrine that the world is constituted by the objects of actual (and, sometimes, possible) experiences' quoted in McWherter (2013). As such it is opposed to the 'real world' that is created internally through the individuals interpretation of experience.

Critical realism consciously compromises between the extremes described above. It allows that social conditions have real consequences regardless of whether they are observed and identified by researchers, but it also recognises that the concepts themselves are human constructions (Easterby-Smith et al, 2008). This compromise allows that the knowledge is a product of the observers interpretive activity and as such is socially constructed whilst also stating that there is a reality that exists separately from any description or non-description of it. The researcher can therefore construct and share theories about this reality.

Krauss (2005) posits that realism stands between a belief that research is value-free (in positivism) and the belief that research is value-laden (in interpretive research) and is distinct in the belief that research is value-cognizant; conscious of the values of human systems and researchers. Perceptions have an observer-based flexibility and there will be differences between 'reality' and an individuals perception of that reality.

3.5.3 Axiology

Axiology is a branch of philosophy dealing with the nature of 'values' (especially the researchers values) and their role in the judgements made about observations and data. It has an important role to play whenever the epistemological stance moves away from a positivist stance, although even here some bias may be introduced through the researcher's value judgements.

In qualitative research the investigator must acknowledge and be open about the presence of bias and the impact of opinions on the research design. This can stretch from the structuring of the research, through the design of data capture instruments to the final, manual, interpretation of data. It is particularly strong where experiences, attitudes, feelings and perceptions are being assessed.

The researcher can take steps to minimise bias (e.g. questioning approaches, considering alternate view points, triangulation of the investigation), but the bias cannot be completely eradicated where the researcher's judgement forms part of the findings.

3.5.4 Methodological Approach

As the researcher considers the distinctions about reality, their relationship with what is being researched and the role values might take in the enquiry so emerges the 'methodological assumption' - how the researcher conceptualises the whole research process as an entity (Creswell 2007). The next step is to determine the operational research design to address the specific situation. As Easterby-Smith et al (2008) describe it, this combination of techniques is the methodological approach.

As Figure 3.1 at the start of this chapter seeks to highlight, methodological approaches must be consistent with the ontological and epistemological stance determined by the researcher. None the less there are a number of choices of approach to be made.

Inductive v. Deductive inquiry

The first decision point for the researcher is to consider whether inductive, deductive or cooperative inquiry is the appropriate approach to follow.

Inductive theory looks to the researcher to infer the implications of their findings for the theory that under-pinned the research exercise. The findings are used to develop the theory onward and the research findings become associated with a particular domain of enquiry. The updated theory becomes the output of the research. The researcher must draw out generalisable conclusions / inferences from the observations (Bryman, 2008).

By contrast deductive theory requires the researcher to derive a hypothesis, or series of hypotheses, from existing knowledge about a particular domain and / or theoretical considerations of the same domain that can then be tested. The step from a hypothesis to operational terms that can be acted upon can be a complex one.

The two approaches above can be characterised and compared as follows (after Daft, 1983); deductive research proceeds from theory to data (theory, method, data, findings) while inductive research proceeds from data to theory (method, data, findings, theory).

Experimental Methodological Approaches

The canonical form of experimental methods require the researcher to maximise control over any factors that may have an impact on the result of an experiment (Gray et al 2007). Such experiments will normally be conducted within a controlled environment to remove uncontrolled variables, so-called 'laboratory conditions'. The goal of the researcher is to infer new knowledge and theory through verifying, falsifying or validating a hypothesis. In fitting with a positivist epistemology and objective ontology, the researcher must dissociate themselves from the subject under study to ensure the robustness of the experiment. External bias that can influence the results must be identified and countered in the experimental design.

Beech (2005) lists types of experiments fitting this approach:

- Classical experiment – subjects are randomly assigned to the experiment or control group. Blinding may be applied to reduce bias. Conditions for the experimental group are manipulated by the researcher (independent variable). Effects of the manipulation are measured (dependent variable) and compared with the same phenomena for the control group. Validity can be statistically inferred by comparing the responses of the experimental group and the control group.
- Quasi-experimental – the research situation makes it impossible to randomly allocate to the experimental and control groups. Care must be taken to address the impact of external bias e.g. the placebo effect.
- Natural experiment – in this case the experimental conditions arise naturally and are not directly controlled by the researcher
- Retrospective experiment – where the researcher observes (measures) an existing condition and looks backwards in time for explanations

Survey / Questionnaire

Moving on from experimentalist methods but staying within a positivist / quantitative paradigm is survey methodology. Such methods are aiming to gather facts and numbers that sit within a relevant construct. The tools used may include:

- Questionnaires / surveys
- Interviews
- Focus Groups

The methods are used to construct a broad-based view of a subject through the collection and combination of multiple sources of data.

Easterby-Smith et al (2008) identify 3 types surveys, *factual, inferential* and *exploratory.* Of these types of surveys Easterby-Smith et al identify the *inferential* survey as most relevant to social science research. Such surveys aim to establish relationships between variables (predictive and dependant). There may be pre-existing hypotheses or assumptions regarding the relationships or not. The term predictive variable is used in preference to ‘independent’ variable as this independence is frequently debatable.

Creswell (2009) offers a different sub-division of surveys – into either descriptive or analytical. Descriptive approaches seek to give insights into the status of a situation to build an understanding that is otherwise lacking. Analytic surveys seek to articulate the relationships, examining correlations and demonstrating cause-effect relationships.

Case Study

As described by Easterby-Smith et al (2008), Case Study looks at a single, or small number, of ‘*organisations, events, or individuals, generally over time’*. The goal is to contribute to the knowledge of individual, group, organisational, social, political and related phenomena (Yin, 2003). The distinctive need for this particular methodology comes from the nature of complex social phenomena.

Creswell (2007) distinguishes Case Study from Ethnography (which also deals with the whole culture sharing group) as the intent is on understanding a particular problem or issue where the case is a specific example, rather than how the culture works.

There is a critique of Case Study (summarised in Creswell 2007) that it is not a methodology but merely a choice of what is to be studied. This is countered by the exposition of case study as a qualitative research methodology in which the researcher investigates a bounded systems or systems over time.

Case Study methodologies themselves come in a variety of forms. The number of cases used is seen as a distinction between a constructionist epistemology (single case) and a relativist or positivist epistemology (multiple cases) (Easterby-Smith et al 2008). Creswell (2007) makes a distinction based on intent:

- Single instrumental case study: the researcher focuses first on an issue then selects a single bounded case to illustrate it
- Collective / multiple case study: the researcher focuses first on a single issue but then selects multiple cases to illustrate the issue
- Intrinsic case study: the researcher focuses on the case itself because the case presents an unusual or unique situation.

The following table sets out key features of Case Study methodology under different ontologies as expressed by Easterby-Smith et al (2008)

Table 3.2: Key features of case method informed by different ontologies

Element	Realist (after Yin)	Relativist (after Eisenhardt)	Constructionist (after Stake)
Design	Prior	Flexible	Emergent
Sample	Up to 30	4 – 10	1 (or more)
Analysis	Across	Across & within	Within
Theory	Testing	Generation	Action

As discussed in the section of epistemology, the researcher must be clear on their position when working with case study method to ensure an appropriate approach to validity.

As Yin (2003) makes clear, addressing positivist concerns about rigour requires the researcher to produce clear designs prior to data collection e.g. main propositions, the unit of analysis, linkage between data and propositions, procedures for interpreting data. In contrast constructionist cases are less concerned about generalisable results and more about providing a rich picture of the situation.

Ethnography

Creswell (2007) summarises ethnography as:

> *"a qualitative design in which the researcher describes and interprets the shared and learned patterns of values, behaviors, beliefs, and language of a culture-sharing group"*

The research must, therefore, focus on a whole cultural group. Such groups may be large (staff of a university, a village community) or small (a research team in a department of the university, a village community council) but it must be the whole that is being researched.

The process of ethnographic study involves extended observation of the group, either as a covert observer or, more commonly, as a participant observer. Ethnographers study the meaning of the behaviour, language and interaction amongst the members of the culture-sharing group through immersion in the normal daily lives of the group.

Participant observation allows passive observation to be supported by interviews with individuals and groups. Covert observation is more problematic in practical terms but nonetheless has an important role in certain types of study.

Easterby-Smith et al (2008) identify the following key features of ethnography study:

- Breakdowns – where the researchers past experience gives no help in understanding what is going on (in-jokes are given as an example). These are an important because they represent something unique about the culture.
- Emic perspectives – this builds on the recognition that there are sounds in language that are only discerned by speakers of that language. It is taken to signify the 'inside-out' perspective of the culture
- Etic perspectives – this is in contrast to the emic perspective and refers to an 'outside-in' perspective. The linguists differentiation is sounds/patterns that are apparent to non-speakers of a language and not discerned by the speakers.

Constructing both perspectives is useful in developing the ethnography.

Grounded-theory

The intent of grounded theory is to generate or discover a 'theory', i.e. an analytical representation of a process (Creswell 2007). The differentiator for grounded theory methodology comes from the insight that the theory-development does not come 'off the shelf' (synthesising or extending from existing theory), it is instead generated or 'grounded' in data and experiences from participants who have experienced the process in question.

In contrast to ethnography methodology discussed above, the researcher is not looking at the whole group, but working with a selection of experienced participants.

Grounded theory was first established by Glaser et al (1968) who saw a role for the researcher to develop theory by comparing the same process in different settings and or situations. Such a theory could be both *substantive* and be generalised into a *formal theory (*Easterby-Smith et al, 2008). Their work argued against the tendency of sociology research to focus testing of hypothesis derived from a few specialised theorists (Locke 1997).

Grounded theory can be criticised as a methodology from promoting a vague approach to a topic without a clear idea of where it is 'supposed' to lead. This discussion was at the route of a public disagreement between the authors on the role of presupposition in grounded theory research. (Locke 1997). The substantive outcome of this is that while there may be different approaches to Grounded Theory, the researcher must be explicit about their own position when completing their research (Easterby-Smith 2008).

Creswell (2007) advances the systematic approach of Strauss and Corbin because of its accessibility to people learning about Grounded Theory. The following procedural steps are proposed.

- The researcher should begin by confirming Grounded Theory is required. Symptoms could include the lack of a pre-existing theory, existing models that are not tested within the situation being looked at by the researcher, the theories that exist are considered to be incomplete
- The research questions constructed will focus on investigating how individuals experience the process and on identifying the steps in the processes
- The questions may be addressed through interview (the most likely method) but the researcher may also collect other forms of data such as direct observations, documents or recordings. The goal is to gather enough information to saturate the model.
- The analysis proceeds in stages:
    - Open coding where the researcher forms categories of information and within these categories identifies properties (or sub-categories) with data that can show the possible extremities of that property (or to set dimensions on it).
    - Axial coding where the researcher assembles the data in new ways after open coding. The coding is presented via a logic diagram (visual model) or coding paradigm where a central phenomenon is explored via causal conditions, strategies for action, context and consequences.
    - Selective Coding where the researcher specifies hypotheses or propositions that state predicted relationships. This may be less formally a ‘story line’ that connects the open coding categories.
    - Conditional matrix where the researcher generates a visual model (the conditional matrix) to show the social, historical and economic conditions that influence the central phenomenon.
- The final result is a substantive level theory written about a specific problem or situation. This substantive level theory may then empirically verified with quantitative data as a step towards a generalised theory (formal theory).

Action Research

Action research seeks to make a virtue of the researcher's influence on the phenomena being investigated. The research is framed as a collaborative enquiry between the researcher and the 'setting' (usually a group or organisational unit). It is expected that the researcher has a high level of involvement in the study setting.

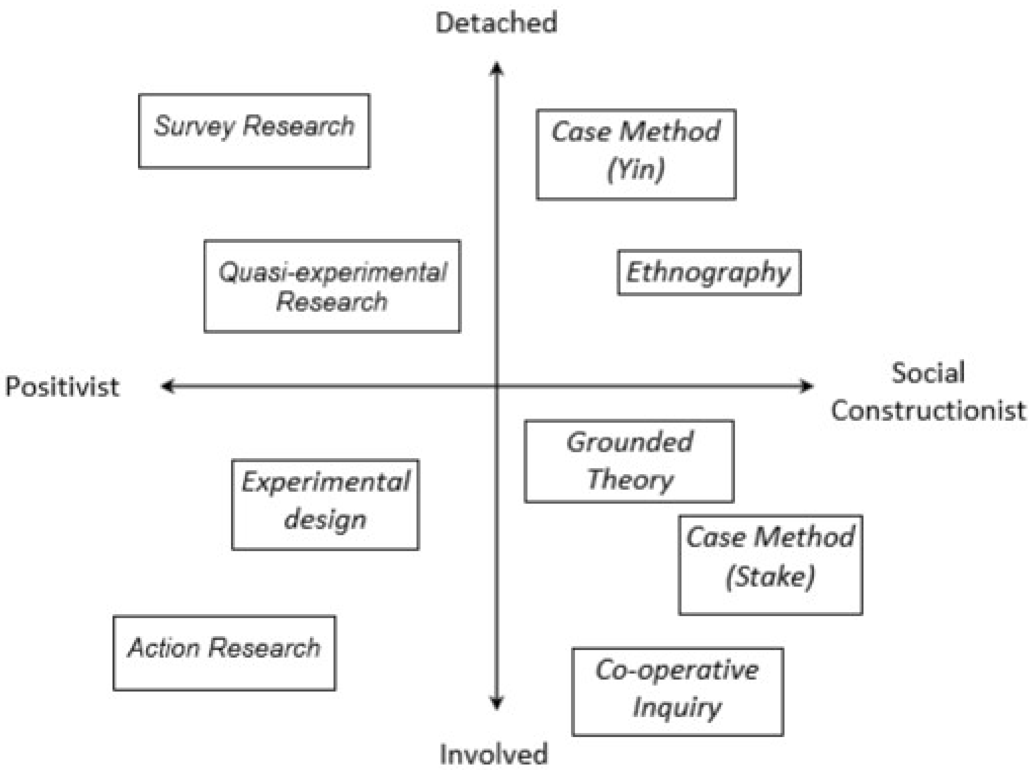
This methodology is associated with the following core beliefs (Easterby-Smith et al, 2008):

- The best way to learn about an organisation (or other social system) is to try to change it. Change should therefore be an objective for an action researcher
- The people most likely to be affected by the change, or be involved in implementing the change should as far as possible be involved in the research process under-pinning the change

Action research is criticised regarding its credibility and robustness in part because of the subjectivity inherent in the study (Huxham and Vangen, 2003). This criticism is balance by the experience of its effectiveness in creating tools and methods to build up theory relating to policy implementation and practice oriented theories relating to management processes (Huxham and Vangen, 2003).

These various methodologies may be mapped against their epistemological stances and the level of involvement of the researcher as follows:

Figure 3.3: Relationships between epistemology, role of the researcher and available methodologies



3.6 Positioning the research – choices made

In this section, the chosen ontology, epistemology and methodology that assure the quality of the research and provide its structure are discussed and justified.

3.6.1 Subjective ontology (qualitative)

As discussed previously, the explicit recognition of the ontology the research operates under is a foundation stone for the quality and validity of the final research outcomes. To operate within an inappropriate ontology risks making errors that invalidate findings.

Ontology is the nature of reality from the view point of the researcher and it is largely the researcher's own background that sets their world-view on this. It is, however, necessary to consider the context within which the research will take place, and be cognisant of the graduation between the text book extremes.

Whilst this researcher has a long professional career in reductionist approaches to problem solving, dealing with measured cause and effect, it has to be acknowledged that systemic enquiry has a strong subjective ontological bent. As Checkland (1999) states 'the system is in the eye of the beholder' and so to ignore subjectivity is to risk substantial misunderstanding later in the research. The understanding of the ontological basis of this research needs therefore to be carefully examined.

Checkland (1999) places system thinking and enquiry in the border country (on the border is too definite) between natural sciences and social science. He shows how the natural science approach runs into difficulty when the object of study cannot be isolated and complexity becomes a defining feature of the observed behaviours (the weather is a classic example). None the less Checkland does see the role of systems enquiry to develop reproducible results in terms of patterns of behaviour and some predictive power to the review of situations. Senge's system archytypes are an example of this (Senge 1994). Social science approaches are critiqued by Checkland (1999) for their, as yet, limited ability to support such outcomes.

The ontological position of a systems world-view is also complicated by the division between hard and soft systems approaches. Hard systems approaches are exemplified by Systems Dynamics (see Meadows, 2008 for a primer) where behaviours are modelled as stock and flows of quantified parameters. Function modelling (e.g. using IDef0 standard) is another. Soft Systems Methodology is Checkland's own contribution (outlined in Checkland 1999) and can be joined on the 'soft' side of systems enquiry by exploratory techniques such as cognitive mapping (see Eden, 1988 for an exposition).

The nature of enquiry in these approaches is:

- to develop an understanding of the behaviour of the whole
- to formulate a description / schema / model of the industry as a whole
- to consider whether actions can be identified and taken to promote desirable outcomes for the whole

Reductionist approaches to such research have been considered and a full critique of those efforts can be read in chapter 2. To summarise here, the identified lack in extant approaches has been to miss any insights into how to deal with a particular case of an industry (rather than a particular firm in an industry, or the behaviour of industries in general at a particular stage). The implication is, therefore, that this type of research is too complex and subjective to be effectively studied by purely objective means. This warrants the need for a subjective approach to data collection in a bid to provide the most complete view of the behaviours of an emergent industry.

However one conceives of an industry, it is clearly *constructed* by the actions of the humans that operate within the boundary. Such actions come from the individuals' own thought process, own rationality and personal philosophy. This is what Checkland defines as a Human Activity System (HAS).

The ontological basis for this enquiry is, therefore, acknowledged to be subjective. The research is focussed on developing ideas and models (theory) through the inductive process. Rich data is required and while elements can be quantified (e.g. number of turbines installed), it is the qualitative understanding that informs the research (does the successful installation of a wind farm constitute a healthy industry or just a successful project task).

3.6.2 Interpretivist Epistemology

The epistemology in a research design represents a general set of assumptions about the best ways of inquiring into the nature of the world (Easterby-Smith et al. 2009). It is clear that an entirely Positivist stance is inappropriate – systems have subjective aspects that are hidden to objective enquiry. Equally, systems have an emergent existence that is independent of any individual viewpoint. That emergent behaviour, think flocking birds, can only be recorded as a whole and that behaviour may only be apparent in objective data. The concern is that a purely Social

Constructionist stance will fail to fully address the issue. The researcher's epistemological stance must be carefully considered.

As set out in the earlier discussion, epistemological stances sit within a spectrum between the positivist – constructionist extremes. This study sits in the boundary area between critical realist and interpretivist epistemology.

Leaning to a realist stance it may be argued that as an emergent entity a system is no less real than a human being. While the actions and behaviours cannot be completely understood in terms of physics and chemistry, the reality of the human beings existence is independent of the observer and can be measured without judgement from the observer. Moving to an interpretivist stance the researcher may argue that understanding the patterns of behaviour of this human being can only come from the observer interpreting these patterns.

Boulding's hierarchy (Boulding, 1956) helps to add a deeper context to epistemology in systemic enquiry. This hierarchy, moving from the purely mechanistic through to the transcendental, suggests changing appropriateness of epistemology as the hierarchy is moved up; the mechanistic is open to reductionist enquiry, for the transcendental the 'whole' is pre-eminent. Further, Boulding states that for a given level in the system hierarchy understanding must be developed within a system at the next higher level.

The system being studied here lies at a higher level in the hierarchy (it is a 'socio-technical' system) and as such its independent reality is only directly accessible by transcendent systems of knowledge. As this is beyond the capability of this researcher the critical realist stance is not appropriate. An interpretivist epistemology is therefore recognised as the stance under which this research is undertaken.

From Klien & Myers (1999), with an interpretivist stance, knowledge of the subject is gained through social constructions such as language and shared meanings. The authors state there is no pre-definition of dependant and independent variables – this is particularly relevant in systemic enquiry where cause and effect are often obscured due their separation in space and in time (Senge et al, 1994). Finally they identify that the focus is on the complexity of human sense-making where the researcher attempts to understand the phenomena through the meanings assigned to them by participants.

3.6.3 Case Study Methodology

Having recognised the subjective reality of the research topic and having determined that the most appropriate stance is interpretivist, the researcher can discount the Hypothetico-Deductive methodological approach.

This leaves a choice between an inductive methodological approach or co-operative enquiry. Co-operative Inquiry is described by Heron (2006) as a way of working with people (in contrast to *on* people) with similar interests to;

- *'Understand your world, make sense of your life and develop new and creative ways of looking at things.*
- *Learn how to act to change things you may want to change and find out how to do things better'*

The approach is well suited to theory building and has an attractive drive for practical impacts and outputs rather than intellectual constructs, given the goal of the research is to strive towards actionable insights. Countering this is the feature of co-operative enquiry that '*all the active subjects are fully involved as co-researchers in all research decisions'* (Heron & Reason, 2006). This would be problematic to address within as large a group as an industry. Easterby-Smith et al (2008) identify the methodology as being directed mainly at individual and community level.

Inductive enquiry's approach to theory building is for the researcher to draw '*generalisable inferences out of observations*' (Bryman, 2008). The researcher is separate from the situation being studied, and that separation is not the source of error or a reduction in validity. Inferences are considered in the light of pre-existing theoretical constructs that prompted the research exercise and the findings are fed back into the stock of theory.

An Inductive approach is considered most appropriate for this study. As the literature review has shown a body of knowledge does exist in the general area of new industry emergence, and the theory building goal is to build upon this from experience of a specific situation, bringing in other theoretical constructs (systems theories).

With the research paradigm choices already recognised, the design moves to consideration of appropriate research techniques to be followed. A number of approaches can be considered closed given the ontological, epistemological and methodological choices, viz:

- Experimental – inappropriate in this paradigm

- Statistical Testing – inappropriate in the paradigm
- Participation – overly 'social constructivist' in epistemology and problematic due to the scope of the enquiry

The following approaches are therefore considered:

- Grounded theory: This would meet the goals of theory building in the field. Its allowance for rich data would be relevant for the area of study. However, the high degree of subjectivity would place limits on the validity and reliability of the data. In ideal form, the researcher would enter the field with no preconceived ideas. After 30 years experience with industry, this would be hard to justify for this researcher.
- Ethnography: This method would allow for the whole to be the focus of the research. The scale of a whole industry is not insurmountable (in the case being considered, there are a manageable number of contacts) but there are valid questions about the extent to which such an emergent industry acts as a whole, and whether a common culture is established. Examples may be; Where do they meet and interact? Is there a common culture?
- Survey: On the more positivist side of the chosen paradigm survey methods might be considered. This would allow a broad based view of the research topic and would incorporate multiple sources of data. However the goal of establishing relationships between pre-defined variables (predictive and dependant) is problematic. The proposed systemic nature of industry emergence obscures (or in extremis, refutes) cause and effect relationships and in any case availability of even potential variables is lacking.
- Secondary data analysis: This method is certainly practicable within the research context. There are a lot of data on the activity of bodies with an interest in the industry's deliverable outcomes. As a single method, however, such analysis would preclude the inferences possible from the views and experiences of the people that make up the industry. This limits the insights that may be gained and can be considered too far on the positivist side of the methodological spectrum.

Case study is chosen as the most appropriate methodology for this study, both through its 'fit' to the research in question and through elimination of alternatives. The goal of such research – to contribute to the knowledge of individual, group, organisational, social, political and related phenomena (Yin, 2003) is a good fit for the intent of this study. The recognition that the study looks at the context over time (Easterby-Smith et al 2008) is highly relevant for a dynamic situation such as industry emergence. Numerous authors have recognised Case Study as an effective approach for capturing qualitative data (Creswell 2007, Easterby-Smith et al 2008, Eisenhardt 1989).

The definition of Case Study in Yin (2003) closely aligns with this research. It is described as;

> *"an empirical inquiry that investigates a contemporary phenomenon within its real life context, when the boundaries between phenomenon and context are not clearly evident, and in which multiple sources of evidence are used"*

The need for Case Study arises where the researcher is attempting to build an understanding of complex phenomena and retain the meaningful characteristic of the real life events as a whole. It is relevant where research questions seek to explain some current circumstances or events – building an understanding of how or why a phenomenon works.

In later writing Yin (2003) makes clear that concerns about validity and rigour may be addressed by particular attention to the case studies structure prior to the commencement of research as identified above. This is contrasted by a more purely constructionist approach to case research where validity is a lesser concern and the output is a rich picture of life and behaviour in groups [Easterby-Smith 2008]. Such studies are investigated by Stake (2006) who distinguishes between instrumental and expressive studies. Instrumental studies look at specific cases to develop general principles. Expressive studies look at cases with some unique or distinguishing feature which may not be generalisable later – this may be a single case in a given study. In such studies the design may emerge through iterative interplay between the data (observation) and reflection (theory).

Eisenhardt (1989) summaries how a broad span of case methods can be used to robustly contribute to theory building. Through examination of theory building case research Eisenhardt synthesises a process for such studies. This research will follow that process with some modification in the light of working with a single case.

The process is outlined in table 3.3 below.

Table 3.3: Eisenhardt Case Study process

Step	**Some activities/rationale**	**Status before field research**
Getting started	Define Research question and possibly, a priori constructs	
Selecting cases	Specify population and make theoretical, not random sampling	

Crafting Instruments and protocols	Create multiple data collecting methods and attempt multiple investigators to strengthen grounding of theory	
Entering the field	Overlap data collection and analysis to allow investigators to take advantage of emergent themes and unique case features	Addressed in Chapter 4
Analyzing data	Analyze within case and across cases	Addressed in Chapters 4 and 5

Step	**Some activities/rationale**	**Status before field research**
Shaping hypotheses	Iterate tabs for each construct and replicate logic across cases and search for 'why?' to sharpen definition, validity and measureability	Addressed in Chapter 4
Enfolding Literature	Compare with conflicting and similar literature to build internal validity, raise theoretical level and definitions as well as sharpen generalizability	Addressed in Chapters 4
Reaching Closure	End process iteration when marginal improvement becomes small	Addressed in Chapter 5 and 6

The research can be considered to fit with the descriptive / exploratory classification of research (after Yin 2003). There is a general lack of case research on emerging industries ([find that quote!]) making the description of an industry through its emergence of value in and of itself, and the goal of generating actionable insights is, at this stage of knowledge, an exploratory activity building understanding and potentially uncovering unexpected discoveries.

The criticism of case study methodology that it lacks generalisability is frequently addressed via 'across case' comparison (after Eisenhardt, 1989). As argued in the next section, a multiple case approach is not practicable for this research. This makes triangulation within the case all the more important if the validity of findings is to be assessed, and the number of generalisable conclusions maximised. The general design of the study is to use multiple independent sources and types of data to provide as much triangulation as possible. Section 4.7 below covers the data collection in more detail.

3.6.4 Case Selection

Having chosen the Case Study approach as the most appropriate methodology to support this subjective / interpretivist research, and leaning towards a relativist position for the study, the canonical (after Eisenhardt 1998) approach would be to sample multiple cases – albeit a small number, 4 to 10 cases being the proposed scale.

This study will look at a single case – that of Offshore Wind Power. There are a number of research and practical reasons for this ‘off protocol’ approach.

To deal with the practical issue first of all; in any given period there is a limited availability of industries in their emergent stage to be studied. At the time of writing there is a rapid increase in the development, deployment and production of technologies relating to low carbon energy which provided a greater opportunity than this researcher has known previously. Some of these will become industries in their own right, some may only ever subsidiary to the industry the technology grew from and some may not last beyond some initial trials.

Examples of these industries include:

- Tidal stream energy
- Wave power
- Solar Photovoltaic (PV)
- Biomass thermal generation

In the years since this researcher’s first graduation (1985), the researcher can only point to the following industries having emerged in the local geography (UK):

- North Sea Oil & Gas
- Financial services
- Games
- Mobile telephony

It could be considered that the recent period has marked a significant up turn in the rate of change of the industrial landscape providing an unusually rich environment to search for suitable cases.

As well as the obvious practical issue of availability of an industry to study, there is a practical issue around the scope of the industry. As discussed extensively above, it is important to consider the ‘whole’ of the industry in this research. To explain the impact of this once can consider the Solar PV industry. In the UK, the primary actors are a large number of small businesses providing installation. The Solar Trade Association (an industry body) estimated in 2015 that there were 670,000 household installations in place [accessed at STA]. Interacting with the whole industry within the UK would be problematic. One would also need to consider the relevance of ‘new build’ solarPV, where the panels are included in a new house, as a distinct sub-set from retro-fitting (the main activity). This issue would now be further complicated by the development of solarPV farms producing grid electricity. The problem extends when one considers the whole supply chain. Solar panels are not made in the UK but in the USA, Europe (Germany) and in China. In 2013 the EU imposed a minimum price on Chinese solarPV imports. It can be considered then that the EU legislative environment and the global solarPV producers are a part of the industry – further growing the scope of the research context.

There is also a reasoned argument for single cases per se. At an early stage of theory building, capturing and exploring the data is of value and contributes to knowledge itself. Siggelkow (2007) makes the point that even a single case can test theory. His example is that we only need produce a single talking pig to dispute the commonly held theory that pigs can’t talk.

It is recognised that the ‘talking pig’ can be argued against for this work. It can simply be stated that new industries are known to emerge. However, as the literature review has determined the availability of case research on emerging industries is severely lacking. There is value in a comprehensive documenting of the industry’s emergence, even if the opportunity for generalisation is reduced due to the lack of direct comparators.

As a case for study, the nascent offshore wind power industry has a number of beneficial features that make it an appropriate case for study.

National Importance

At the commencement of the study, both the UK government and the Scottish government had set themselves challenging targets for the reduction in CO2 from electricity generation. All generation technologies were seen as important, but onshore and offshore wind were given particular focus. It was reasonable to suppose that any legislative impact on the industry would be intended rather than a side effect of other policy stances.

Scale

The potential for the industry pointed to a significant possible scale. If the industry was maximally successful in developing and installing capacity, it would be capable of producing the average demand of UK electricity (40GW – UK average electricity demand in 2017 was 38.5GW [UKGOV figure for total generation of 335.9TWh]).

Equally, at the projected scale, the UK would be the largest market for offshore wind power in the world. At the commencement of the study the UK already had the largest share of offshore wind generating capacity in the world. This would address the concern of being unable to access the 'whole industry'. It could reasonably be proposed that the industry would come to the UK. This is in contrast to the Solar PV example discussed earlier.

Technology

Onshore wind power generation had already demonstrated that the basic technology was capable of producing large scale power. Although the technology was not without challenges, the risk that the industry would stall due to limitations in the basic technology was low. Again this can be compared to both wave power where there is a long record of power generation technologies that have failed to progress. Similarly tidal stream does not yet have a credible generation technology despite a number of potentials being tested.

Distinctiveness

A discussion point for any emerging industry is to question whether it is a special case of an existing industry or has sufficient features to distance itself from any extant industry. A current example might be electric vehicles (EVs). The main components of volume EVs are different from internal combustion engined (ICE) – powertrain, energy storage, braking systems, chassis, electrical systems, HVAC etc. It may be argued that this is a different industry. However outside of the USA (where Tesla now has a leading position in sedan production for any power source – in part because the USA buys so few sedans) the EV producers are the same companies as ICE producers.

Offshore wind power does have a number of features in the UK to distinguish it from other power generation technologies. The underpinning technology is the same as for onshore wind, but the scale of the offshore projects is larger than for onshore wind. This is driven by the leasing mechanism (a single body is responsible for making any sites available to offshore wind developers) and the complexity of marine construction (all the onshore requirements still exist plus the additional skills and technologies required to operate offshore). Neither is likely to change; the marine environment is more hostile and any access requires far more infrastructure (vessels, divers, platforms etc.); gaining planning consent for large wind farms (in the order of 100 turbines) onshore is equally challenging.

In comparison to typical generation infrastructure development, offshore wind has a greater 'serial production' element. Multiple sites of tens or hundreds of wind turbines are required to meet the generating capacity of a single thermal generation plant which may have only a handful of generating units e.g. Drax Power station has 6 off 660MW generating units.

It is therefore reasonable to expect that a very different grouping of involved companies, operating different processes and protocols will come together to make up the offshore wind power industry.

These features together make offshore wind power a good candidate for a research study into emerging industries – particularly where the focus is on a single case.

3.7 Data Collection

Having chosen a fitting research paradigm the researcher must consider what data are going to be collected and what techniques will be employed in this endeavour. As has been identified above, Case study research takes data from a wide number of sources. This is particularly important where description and exploration are key aspects of the research.

Yin (2003) identifies six distinct sources of data. These are:

- Documents - any media relating to on-going practice within an organisation
- Archival records - formal records and external data sources
- Interviews - structured or unstructured discussions with actors
- Direct observation - non-participatory observation of the phenomena and its context
- Participant observation - active involvement of the researcher in the phenomena of interest within its context
- Artefacts - inspection of the physical context or result of the phenomena

This study will make use of the following techniques:

- Archival records: These will be publicly available records that identify what the industry has achieved, what issues it faces, what restrictions it faces. These may include, but will not be limited to, government publications, industry reports, newspaper articles, company reports.
- Interviews: Interviews will be held with selected individuals who have significant experience of the industry from within active roles in the industry – industrial, governmental and supporting organisations. These interviews will follow a semi-structured format outlined

in a data collection protocol in Appendix 3. These interviews will be supplemented by unstructured interviews with other participants in the industry.

- Observation: As stated in the research paradigm, a ‘whole’ view of the industry is important. A consistent way of observing the industry over time was therefore important. The annual Offshore Wind Power Conference organised by Scottish Renewables was chosen as an accessible forum for observation that would highlight what the industry was doing and that would maintain a consistent structure over time. The author aimed to make this observation ‘non-participatory’ although some level of influence may be present. This is discussed in more detail below.

To fit with Eisenhardt’s process for building theory from Case Study, the next step of research design is in crafting instruments and protocols.

Yin (2003) makes clear that a high level of prior instrumentation is required to ensure the validity of research findings. It is recognised that this view fits with a positivist stance and may be inappropriate where the research is more constructivist in nature. Thus the level of prior instrumentation can be expected to vary substantially between research designs as a direct result of their different nature.

The goal of the prior instrumentation is then to create a structure that helps guide the collection of data (to avoid ‘getting lost’ in possibilities and never constructing a coherent data set) without overly constraining the data collection (where a rich seam of data is ignored because it doesn’t fit the protocol).

Miles and Huberman (1994) set out a number of factors that can guide the researcher in their decisions over the level of prior instrumentation (see table 3.4 below).

Table 3.4: Determinants of level of prior instrumentation

Little prior instrumentation	*Placement*							*Extensive Prior instrumentation*
Rich, context description required	■							Context less crucial
Concepts inductively grounded in local meanings			■					Concepts defined ahead by researchers
Exploratory, inductive		■						Confirmatory, theory driven
Descriptive intent		■						Explanatory intent
‘Basic’ research emphasis		■						Applied research, evaluation emphasis
Single case		■						Multiple cases
Comparability not too important			■					Comparability important

Simple manageable single level case			■					Complex multi-level case
Generalising not a concern			■					Generalisability important
Need to avoid researcher impact				■				Researcher impact lesser concern
Qualitative only				■				Multi-method, quantitative included

The above table endeavours to set out where the author considers this research to sit within the spectrum between little instrumentation and extensive instrumentation. As can be seen, the nature of this research leans towards little instrumentation while certain aspects suggest a degree of prior instrumentation.

The following sections describe the levels of instrumentation used for each aspect of the case (archival records, interviews and observation).

3.7.1 Archival records

The following archival records were identified as being of particular relevance to the case:

- RenewableUK (BWEA) wind energy database: This provides a record of the number and scale of wind farm sites in planning, under construction, and in operation. The data covers both onshore and offshore. The data is publicly available and is continuously updated. An extract of the database covering offshore wind sites was taken twice per year (in spring and autumn) so that the progression of sites in construction could be maintained.
- UK Government Renewable Energy planning Database: This data set is managed for the department of Business Environment and Industry Strategy. It covers all renewable energy sources and supplements the BWEA database with information on planning progress. This database includes dates of changes (e.g. planning submitted, planning appeals, construction start, date operational).
- Press releases relating to the progress of leasing rounds (e.g. intent of the round, number of bids, who succeeded)
- Government data on ROC and CfD levels and changes to these levels
- Industry reports regarding progress – examples are EWEA (now WindEurope) annual report for Europe-wide data, Offshore Wind Accelerator report for progress on cost reduction,

3.7.2 Interviews

Two types of interviews were conducted – early exploratory conversations with individuals involved in the industry (Dawson, Scot Ent, Kevin Moran, Andrew MacAskill) and later in-depth interviews.

The first stage interviews were attributed and unstructured discussions of an exploratory nature. Written notes on the meetings were captured at the time (see Appendix 1).

The second type of interviews followed a formal protocol as proposed by Yin (2003). Interviewees were selected to represent the core organisations in the industry (developers) and closely linked supporting organisations. These roles are explained more fully in section 4.5.2.

The interviews were semi-structured and sought to probe key aspects of the industry that had been observed by the researcher. Interviews were recorded (see Appendix 1) and reported anonymously. The protocol was designed to support case the layering of analysis described by Yin (Yin, 2003) as follows:

Level 1

The first level of questions structures the conversation to be had with the interviewee. A group of 10 core question areas were defined that allow the researcher to investigate the interviewee's experience and understanding of the industry without leading them.

Level 2

These core questions are structured to allow a second level of analysis which uses the data obtained in conversation to address the core case questions of:

- Does the participant consider OWP an industry?
- Does the participant recognise the described sub-systems of the industry?
- How effective does the participant see the interaction between the sub-systems of the industry?
- What is the participant's assessment of the health of the OWP industry?

Level 3

Beyond this analysis of each interview the researcher can build a third level of review where the collected interview responses are examined to see what consistent patterns exist across the responses. Of particular interest are:

- Is there a congruence in views of challenges faced by the industry (past and future)?

- Do the participants agree on the ‘shape’ of the industry and its constituent activities?
- Are there any divergence of views amongst the interviewees?
- Are interviewees aware of industry activities that do not directly impact them?

The next levels of analysis go beyond the interview responses to integrate them with other sources of data.

Level 4

This level of questions relate to the wider integration of information from the variety of sources to consider the interview responses in light of the whole case. Examples may include;

- What sentiment lies behind the published data on OWP growth?
- What life cycle stage is the industry at?
- Does the industry have sufficient capacity/capability to meet currently visible challenges?

Level 5

The final level of analysis is to consider normative questions about policy recommendations and conclusions which go beyond the narrow scope of the study. This level supports the wider generalisation goal for the research. Questions which may be answered include;

- What is the most appropriate support for emerging industries to enhance their emergence?
- What is the most appropriate role for supporting institutions?

The complete interview protocol is in Appendix 3.

3.7.3 Observation

The Scottish Renewables Offshore Wind Conference and Exhibition was selected as an appropriate environment in which to observe the industry. The events goal is to bring together the industry to discuss issues, disseminate progress and share experiences. As an observer it offers an opportunity to see what types of organisations are interacting with the topic – not necessarily operating within the industry. It is assumed that the workshop topics are those of interest to industry insiders, and how those change over time is relevant to the progression of the industry.

The conference itself is held annually at the same time of year and so provides a stable context in which to observe the dynamic changes of the industry.

The following data are considered to be a core part of the observation:

- Exhibitors at the conference
- Attendees of the conference
- Topics of the workshops / presentations at the conference
- (Themes of the plenary sessions?)
- General 'mood' of the conference

The change in these elements from year to year forms a core part of the analysis.

The author also gains impressions of how the industry thinks it is doing from immersion in the event.

Other sources of observation come from press articles on the industry. In particular, it is interesting to note what editorial tone is levelled towards the industry.

3.8 Data Analysis

The data analysis stage of any research is of obvious importance. Nonetheless Miles and Huberman (1994) suggest that the data analysis stage in qualitative research is regularly carried out badly and they identify the following reasons:

- the difficulty in consolidating and managing large quantities of data of different forms collected via qualitative data techniques
- the difficulty in 'making sense' of such data and so drawing objective (constructed from the presented data) conclusions from rich and extensive data.

These difficulties are compounded by the fact that analysis approaches for qualitative data are tailored to the phenomena being studied and therefore are largely unique. This makes the effort to generalise approaches for later researchers to use largely futile and so the availability of techniques and guides regarding the data analysis stage are limited. This issue helps perpetuate the situation highlighted by Miles and Huberman (1994).

This research has a number of characteristics that reduce the ability of any particular approach to provide a complete framework e.g. it is a single case so all analysis is 'within case', there is extensive numerical data as well as individuals' feelings to be combined, description is important but there are dynamics to be extracted. Authors who offer more general guidance on how to conduct the analysis stage include Eisenhardt (1989) and Miles and Huberman (1994). Their suggestions are utilised to set out the approach to the data analysis in this research.

Following Eisenhardt (1989) the first step is a detailed write-up of the case that does not seek to draw inference but merely to record, at the level of the 'whole', the phenomenon of industry emergence in this case. As it is the emergence that is of particular interest the primary structure of the case is that of a timeline to give a sense of the progression of the group of activities and projects that became the industry.

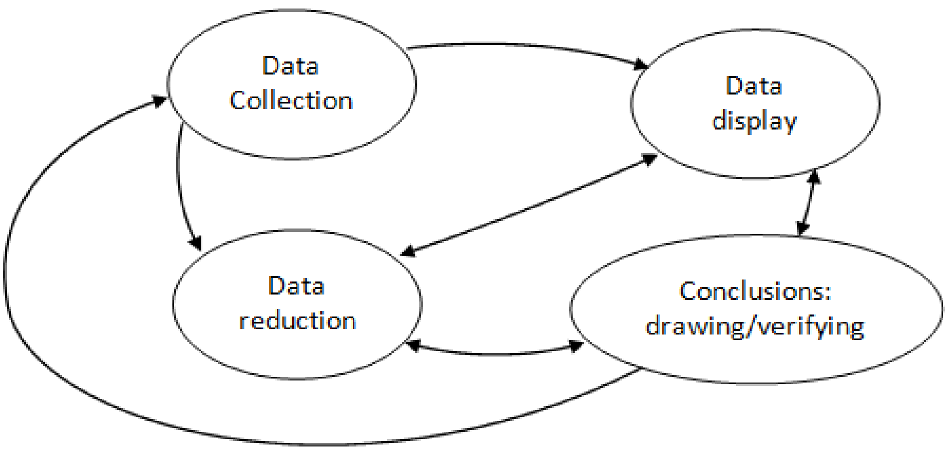
Eisenhardt's next stage is to search for cross-case patterns. While this is not achievable within this research context (of a single case), the discipline of looking for dimensions and categories that may support future cross-case comparison increases the opportunity for generalisable conclusions and is not expected to reduce the descriptive or exploratory capacity of the research.

Eisenhardt (1989) states a goal of forcing the investigator to go beyond initial impressions through the use of structured and diverse lenses on the whole data set. The strategy of dividing data by data source suggested by Eisenhardt is adopted here. This provides a high level of triangulation to the analysis and allows for limited statistical analysis where this is appropriate.

The final stage proposed by Eisenhardt is the shaping of hypothesis. The iterative process described leads the investigator through a number of cycles of developing and refining themes, concepts and relationships and comparing them across different cases (and in this case across different views of the dataset) to home in a theory that closely fits the data.

Miles and Huberman (1994) provide a more focussed approach to the definition of techniques for achieving the within case analysis. They also suggest an iterative approach to the steps of data collection, data display, data reduction, drawing and verifying conclusions as shown in Figure 3.4 below.

Figure 3.4: Measures to facilitate Data Analysis (after Miles and Huberman, 1994)



The goal of this is to introduce a more systematic approach to the analysis to support the generation of rich meaning with regards to industry emergence. Miles and Huberman recommend the following tactics to help moving to conclusions:

- Noting patterns
- Seeing plausibility
- Clustering
- Making metaphors
- Counting
- Making comparisons
- Subsuming particulars into the general
- Noting relations
- Building a logical chain of events
- Making conceptual / theoretical coherence

A further element to consider in Case analysis is raised by Yin (2003). An element of flexibility should be incorporated into planning the data analysis. It is possible, or indeed likely, that the most suitable technique to employ will not become apparent until data have been collected. The iterative approach being described above does allow for this and it is the author's expectation that the relative novelty of a systems approach to industry emergence will require a level of fluidity in the intended use of data. In practice this directs the researcher towards data that address aspects of the whole, rather than data that can be incorporated into an analytic structure.

3.8.1 Unit of Analysis

As identified by Easterby-Smith (2008) the unit of analysis is the entity that forms the basis of any sample. The importance of selecting the 'right' unit of analysis for any study is that it sets the frame in which data are reviewed. Eisenhardt and Graebner (2007) show how each 'case' represents a distinct experiment to be analysed. Easterby-Smith talks of the need for a clear unit of analysis in constructionist research to address the 'seeing the wood for the trees' problem – the complexity of analysis that arises from rich qualitative data.

In this research the unit of analysis is the whole ‘emerging’ industry and data are collected and observations made in reference to the whole. Adding to the ‘wood and trees’ issue are the number of embedded cases (subsidiary units of analysis) possible with this research. Examples include:

- Primary unit firms
- Supply chains
- Industry sub-activities

Existing literature has most to say about the first embedded cases; the final example is highly relevant in ‘system of systems’ enquiry and makes up the embedded case elements of this research. The discussion section in chapter 6 will explore this decision in more detail.

3.8.2 Data Reduction

The data reduction step introduced above is a necessary step in the analysis that helps to ‘sharpen, sort, focus, discard and organise’ data in order to support the researcher to reach conclusions (Miles and Huberman, 1994). This step covers the selection, focussing, simplifying, abstracting and transforming the data that is gathered in all the forms identified previously (interview transcriptions, field notes, reports and industry performance data).

Miles and Huberman (1994) consider that data reduction is a process that is ongoing throughout the course of the research. This process will start even before the researcher begins the data gathering activity with a degree of data reduction occurring, perhaps subconsciously, in the selection of a conceptual framework that is being followed, the determination of the case(s) to be investigated, the research questions used and the data collection methods chosen. One on the strengths of a canonical grounded theoretical study is the reduction (if not removal) of this pre-selection.

Data reduction becomes more conscious as the researcher moves from pure data collection to begin the summation of notes through; noting key aspects; the codification of elements of the data; the search for patterns and themes in the data; the categorisation of codes and themes into clusters; writing brief summary memos.

In this research the exploration is of the emergence of an industry as a whole with the goal to develop insights into how to promote (perhaps accelerate) the emergence as a viable entity. The fuzzy boundary nature of an industry is increased by the nature of an industry in its early stages (how far into the groups of people and organisations who *might* be included does the researcher go), As a result the number of sources of information are vast and a degree of data reduction through the consideration of sources (moving from what could be captured to what must be captured) is necessary just to be practical.

Prior to the commencement of the data gathering it was clear that the following key aspects of the 'industry-as-a-whole' needed to be addressed:

- The dynamics of the whole. What happens to the industry (both internal and external events) over time?
- The experience of involved actors in the industry. How do they 'see' the industry? What do they think about its status? How do they feel about it?
- An external observers view. What activities are being pursued? Who is involved? Who is not involved? What is going on?

This outline structure provides a framework to see the industry as a whole. There is also a level of overlap between the three aspects e.g. what did actors think about key events, how did these events change the activity, what impact on outcomes did the events have. This provides an important level of triangulation across the dataset.

Even given this focussing there is still a large quantity of data collected and so further data reduction is necessary. The following sections highlight the data reduction approaches used for data from each of the three aspects.

Timeline

As identified above this aspect is considering the dynamics of the industry. The data collection focus is on non-repeating events (e.g. enacted legislation) and elements where trends and changes can be observed (number of leases granted, number of turbines erected, length of time to achieve planning, length of time to construct site).

Further data reduction then comes from categorisation, counting, summing and averaging of data where applicable.

Interviews

This aspect is intended to cover the experience of actors within the industry. To maximise the value of each interaction the researcher used a formal protocol for semi-structured interviews (after Yin 2003). This provides a level of data reduction through guiding the conversation between the researcher and the interviewee towards gaining insight about the industry that can be compared to other conversations.

The output from the interviews is then coded to support this comparison.

Observation

The third strand of data collection, observation, also had an element of pre-selection data reduction. The researcher made the decision to base the immersed observation activity on a recurring event for the industry – the annual SR Offshore Wind Conference and Exhibition. This provided a mix of data from the companies that exhibited, to who attended, topics presented and questions asked in plenary sessions.

This data is further reduced via a mix of counting, categorisation and coding.

On Coding

The purpose of coding is to break data up and organise it into categories to facilitate comparisons between things in the same category and to aid the development of theoretical concepts (Maxwell, 2008). As has been highlighted in the immediately preceding sections, coding has a central role in the data reduction strategy used in this research.

Initial coding is a strategy often used to bridge from theory to data collection. Codes are derived from existing theory as it relates to the research questions. This has less relevance here due to the widespread use of systems theory terms in general use whether they are carrying the theoretical meaning or not. Examples of this include system, emerge, feedback, communication. All of these words are used in the context of human activities and may or may not relate to the formal ideas of;

- System – an inter-connected group of entities operating together to a common purpose
- Emergence – an observable property of the whole system that is not apparent within any one of the individual entities
- Feedback – the communication of system output state to system entities' inputs with the intent to modify behaviours
- Communication – the purposeful transference of data between entities

Whilst such terms formed an implicit coding within interviews, further codes were inductively derived from the data during early analysis stages.

3.8.3 Data Display

Following Miles and Huberman's schema above, data reduction is followed by data display. Even after data reduction the researcher will be faced with an extensive range of rich data to absorb and make sense of. The purpose of the data display stage is thus to compress, organise and assemble relevant information (Miles and Huberman, 1994). Miles and Huberman (1994) state that the failure to complete this stage effectively can overload our cognitive faculties and lead the researcher to ‘hasty, partial and unfounded’ conclusions.

The ability to ‘see’ the data helps this by engaging humans’ pattern recognition faculties, offering different insights to the purely cognitive approach. There is a danger in seeing patterns that aren’t there but this (pattern recognition) often provides an useful initial step in an iterative process.

The types of data display that may be used are extensive and could include graphs, charts, matrices, networks, diagrams, rich pictures, illustrations, tables and so forth (after Yin, 2003). The common goal of these tools is that they pull together organised information into a compact format (available at a single glance, not several pages) that allows the analyst a ‘whole view’ in a single stage and thus promotes better understanding of the phenomena under study.

In this study a variety of display techniques are used to make sense of different aspects of the case.

Charting: This supports the display of condensed information on the progression of the industry over 19 years of recorded activity.

Graphs: The performance of some aspects of the industry can be presented to show correlations (or lack thereof) between activity and performance.

Tables: These are used to visually present comparisons of blocks of activity e.g. how different rounds of development compare.

Matrices: Matrices are used to support the review of semi-structured interview responses and the content of successive industry conferences.

Diagrams: In the later stages of analysis it is useful to provide a diagrammatic representation of the industry as a whole.

3.8.4 Drawing & verifying conclusions

The last stage of the process of data analysis is to generate conclusions that draw out or highlight important aspects of the data and show how these can be verified.

As the figure 3.4 from Miles and Huberman (1994) above shows, each of the stages of data analysis can be considered to be interactive and interdependent – data reduction impacts on data display which impacts on conclusions which also impacts on data reduction etc. Drawing conclusions then is not only an end point in the analysis. The researcher can and should go back and forth between the different activities as each stage of the analysis opens up. Drawing tentative conclusions helps reduce data to the most pertinent. This in turn moves the researcher to make sense of this data via appropriate forms of display which may show the tentative conclusions to be illusionary but still develops the central theory. In such cases the researcher is being pointed to the need to collect further data.

Even where the initial cycle supports tentative conclusions, the researcher needs to consider whether these conclusions address the research questions and at a broader level the aims and objectives. Any remaining gaps, or questions to be answered need to be addressed – was the research question naive? Has an important aspect been missed through excessive data reduction? Can the question be better answered via different analysis?

The final stage is when the researcher reaches a satisfactory answer to these questions.

3.9 Ensuring Validity

Qualitative research is often critiqued by observers from a more positive stance as lacking validity due to the impracticality (if not impossibility) of repeat ‘experiments’. Yin (2003) proposes the integration of 4 criteria that can assure the quality of the research and provide the basis for validity of the research. These four criteria are:

- Construct validity
- Internal validity
- External validity
- Reliability

Gibbert et al (2008) build upon this and other work to underline that while all criteria are important, there has been a tendency to over emphasise external validity to the detriment of construct and internal validity which they argue are more fundamental measure in addressing research rigour.

Table 3.5 below sets out elements to consider to increase the robustness of the research when developing the research design

Table 3.5: Elements to consider for increased research validity

Internal Validity	Construct Validity	External Validity	Reliability
Research framework explicitly derived from literature	Data Triangulation Archival Data Interview Data Participatory observation data Direct observation data	Cross case analysis	Case study protocol
Pattern matching	Review of transcripts and drafts by peers	Multiple case studies	Case study database
Theory Triangulation	Review of transcripts and drafts by key informants	Nested approach	Organisation actual name given
	Clear chain of evidence Indication of data collection circumstances Check for circumstances of data collection Explanation of data analysis	Rationale for case study selection	
		Details of case study context	

The following sections explain each criterion and describes how they are incorporated into this research design.

3.9.1 Internal validity

Yin (2003) proposes that internal validity is a concern for *exploratory* type case studies where the goal is to identify causal relationships between factors in the case. Gibbert et al (2008) expand on this to stipulate it refers to the causal relationship between variables and results. They summarise the central issue as whether the researcher provides a plausible causal argument, logical reasoning that is powerful and compelling enough to defend the research conclusions.

This validity is evidenced within the data analysis phase.

In this research design the approach is descriptive / exploratory and Yin's (Yin, 2003) implication is that internal validity criteria are less relevant. The form expressed in Gibbert et al (2008) underscores this by seeking an explicit framework that demonstrates that variable x leads to outcome y (and that y cannot be caused by an unseen third variable z) – something that systems approaches rule out. As Senge et al (1994 pp92) put it;

> *"Cause and effect will not be closely related in time and space"*

This research works within the limitations of the context rather than throwing out the principles of internal validity. The author considers that nothing is lost in considering these principles in the light of the research context e.g.

- Deriving causal maps from the observed phenomena (see chapter 6) is analogous to the causal relationships in the literature of Yin (2003) and Gibbert et al (2008).
- Pattern Matching from the case to existing literature that looks at aspects of industry should not find contradictions, even if the end framework of 'industry as a whole' gives different insights.
- Theoretical triangulation is still valid in the different systems approaches that can be applied.

3.9.2 Construct Validity

Gibbert et al (2008) summarise construct validity as the quality of the conceptualisation or operationalisation of the concept (or concepts) at the heart of the research. Yin (2003) advises the researcher to:

- define the phenomena to be studied in terms of particular elements which are to be focussed on during the investigations
- identify the operational measures that match these elements

For this research key elements / concepts that require conceptualisation include the 'human activity systems' (after Checkland 1999) which describe the activity of the whole industry, the 'signals' (information directed between systems elements, broadcast to the whole or published for general use) which may or may not constitute feedback and emergent behaviours (where the industry as a whole acts in ways that can't be predicted from the behaviour of individual human activity systems.

Operational measures that can be put in place to investigate these constructs come from a mix of pre-definable measures (e.g. constructed wind farms, levelised cost of energy (LCoE) for projects, time to construct wind farms, numbers of industry players etc.) and measures that are emergent as a result of observation.

Gibbert et al (2008) extent the advice to stipulate two particular measures;

- Establish a clear chain of evidence to allow the reader to reconstruct how the researcher went from research questions to the final conclusions

- Triangulate the data collection – find different ‘angles’ or approaches from which to look at the same phenomena

3.9.3 External validity

Gibbert et al (2008) identify external validity with the generalisability of the findings. The goal of generalisability comes from the intuitive belief that derived (or improved) theories must account for phenomena beyond the setting in which the researcher is studying them, i.e. the findings are transferable to other settings.

Gibbert et al (2008) make the point that even in multiple case studies there is no opportunity for statistical generalisation to infer conclusions about a population – instead they point to *analytical* generalisation.

Yin (2003) states that generalisation is not an inevitable step. A theory must be tested by replicating the findings in a separate case. This presents issues for this research design as discussed in case selection – there is a lack of availability of cases of new industry emergence.

As Yin (2003) also states, external validity, for exploratory cases is a lessor concern. Gibber et al (2008) conclude that an over reliance on external validity detracts from the other forms of validity. In the absence of the availability of an independent case maximum use is made of rich details on the case context as a support to external validity.

As a step towards external validity and generalisation, the findings are tested with recent research work on tidal stream energy with the lead researcher.

3.9.4 Reliability

Reliability refers to the absence of random error in any data points. The goal is for subsequent researchers to come to the same insights as the author if they conducted the study again following the same steps (summarised in Gibbert et al, 2008). This is always problematic for case research as the same conditions are hard (if not impossible) to replicate. Gibbert et al (2008) identify 2 main concerns that need to be addressed by case study research design to maximise the reliability of collected data.

- **Transparency:** This is enhanced through the use of measure including careful documentation and clarification of research procedures e.g. producing a case study protocol

- **Replication:** This can be supported through the compiling of a case study database to include observation notes, case study documents, narratives etc. The database should be organised to facilitate retrieval for later investigations.

3.10 Summary of Chapter

This chapter has laid out the research design and framework for the investigation that will provide assurance of the quality of the final outcomes. The various decisions that have lead the author to final design have been explored and the chosen methodological approach explained and justified in the context of the phenomena to be investigated.

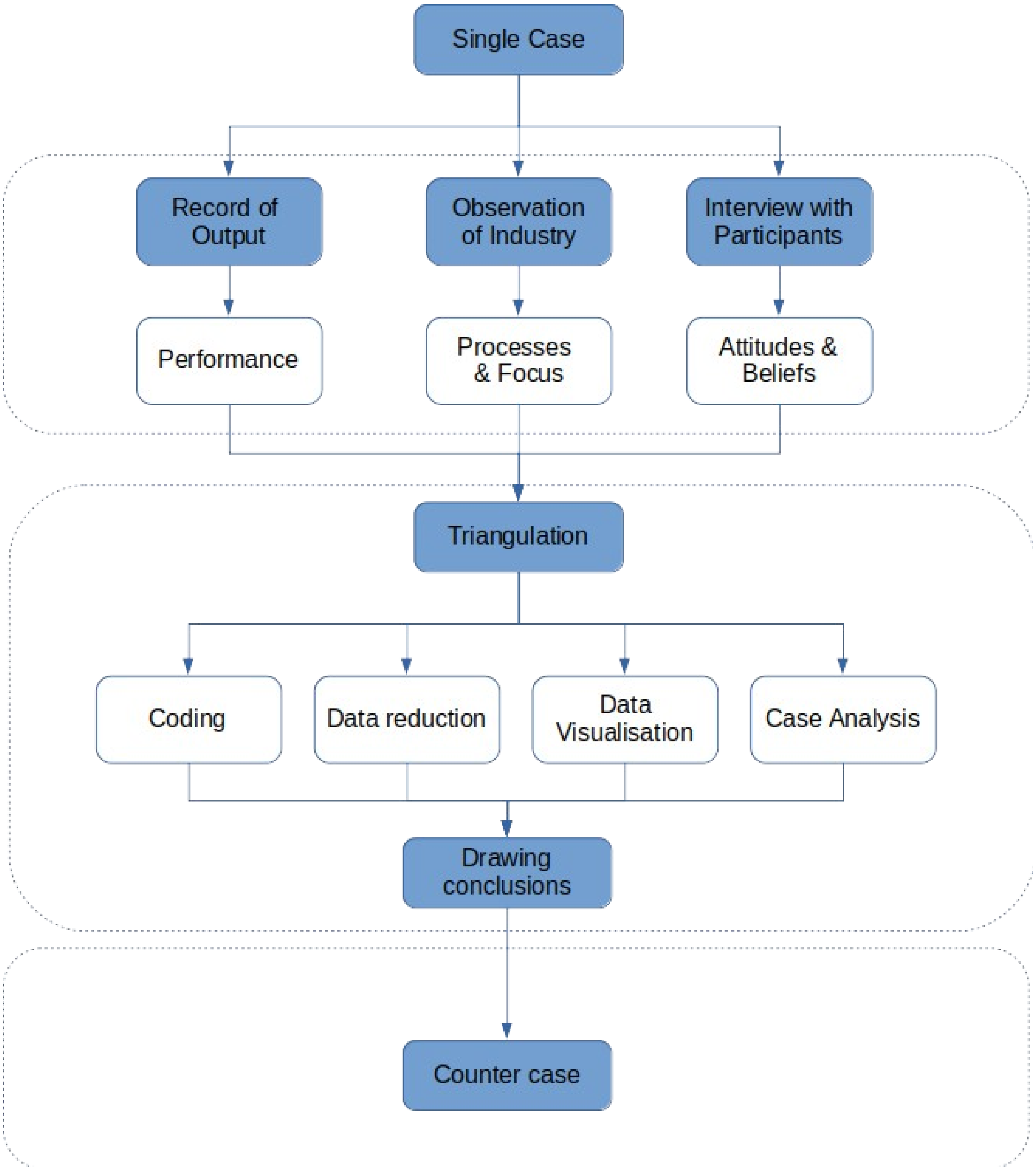
The first link in the chain of design is the setting out of the overall aim of the research and its underlying purpose in the first section. This is then linked to the objectives and research questions asked of the investigation, building upon the existing base of knowledge explored in chapters 2 and 3. These objectives and research questions give structure to the whole activity.

The next section explores the research paradigm and its component elements (ontology, epistemology and methodology) and referring to the earlier work leads to the chosen foundational elements of this research. This in turn leads to appropriate decisions on the measures necessary to ensure the research follows a rigorous protocol from formation, through data collection and analysis to final conclusions.

This exploratory research in conducted within a subjective, qualitative and interpretivist paradigm. It consists of a single longitudinal case study, triangulated via multiple data collection approaches. The use of a single case is discussed at length.

Figure 3.5 below diagrammatically sets out the research activity.

Figure 3.5: Schematic of research design



4. Analysis & Findings

4.1 Introduction

This chapter presents the descriptive case of the offshore wind power generation industry in the United Kingdom. The case has been constructed following a framework of systems enquiry as set out in Chapter 3 – Methodology.

Appendix 4 sets out a timeline of the data sources used and data collection activities.

The Offshore Wind Power (OWP) generation industry has been in development in the UK since 2000. Early promise led to a formal structure to allow OWP within UK territorial waters (out to 12 NM) and the extended economic interest zone (out to 200 miles). It was supported by government as one of the mechanisms to achieve carbon reduction goals set for 2050 (Climate Change Act 2008). This chapter describes the observed industry as it stands at 2018, when the performance towards the 3rd Carbon Budget (2018 - 2022) goals is known (Committee for Climate Change, 2018) and future direction is emerging (a sectoral deal for offshore renewables is in negotiation).

The operational context for OWP is the UK electricity market which started towards its current form when the market was deregulated in 1999 (‘The GB electricity retail market’, Ofgem 2018). What had previously been regional companies tied into the national grid was separated into Generators (who supply a wholesale market), Suppliers (who sell to consumers throughout the UK – the retail market), a transmission company (NGET - providing the backbone element of the National Grid) and Distribution Network Operators (14 regional infrastructure companies who connect up properties to the grid).

The UK electricity market is dominated by 6 companies (British Gas (Centrica), EDF, E.On, nPower, Scottish Power, SSE) who supply 77% of the domestic market (‘Retail energy market charts and indicators ‘, Ofgem 2018). These companies are both suppliers and generators which obscures the wholesale market (or reduces market liquidity) as a portion of the ‘trading’ is done between units within a single corporate structure and actual prices paid is unknown. There is some evidence that market liquidity is improving overtime e.g. reduction in bid spreads for electricity in recent years (‘Retail energy market charts and indicators ‘, Ofgem 2018).

The wholesale market is maintained via the NGET Balancing Mechanism ('The GB electricity wholesale market', Ofgem 2018) which has a 'cost-out' mechanism to incentivise demand and supply balancing, ensuring there is sufficient generating capacity to meet demand.

There are a number of legal instruments which act on the electricity market in the UK. Those impacting the construction and operation of offshore wind farms are described later in this chapter.

The following sections of this chapter will set out:

- a structure for offshore wind power as it exists in 2018
- a time based review of its development towards this form intended to show the dynamics of the industry over time
- a process based review of the key activities identified as relevant aspects of the offshore wind power commercial enterprise
- an observations based review of the industry covering 2 aspects – the 'pulse' of the industry as evidenced by the annual OWP supply chain conference, and the view of the industry as evidenced by participant interviews.
- a review of whether the data gathered addresses the research questions

4.2 Structure of the Industry

The literature on systems, and on industries, makes clear that defining the 'boundary' is non-trivial and analysis-impacting decision for the researcher. At a first pass, the organisations (start-ups, stand-alone divisions and profit centres of large companies) directly involved can be clearly identified. It is also possible to identify those organisations which have a commercial interest (services, products relevant to the industry) or policy interest (government body, industry membership groups, research organisations etc. where terms of reference require or imply involvement). It becomes more complex where the organisation's interest in the industry is influential whether or not it becomes involved e.g. a major utility which could be both producer and customer.

To aid this decision it is helpful to consider the relative impact of the organisation on the industry and vice versa. In this research the industry players are separated into primary, secondary and tertiary groups as follows:

- **Primary:** These are the organisations and institutions that drive how the industry turns out. They set where wind power can be, set the economic basis for supplied energy and integrate technologies such that a financially viable investment is arrived at. The substantive focus of these organisations is on the OWP industry and so the success or otherwise of the industry directly impacts the organisational success.
- **Secondary:** These are the organisations that respond to the requirements of the industry and to the primary organisations. Equipment manufacturers and service organisations do this through contractual (e.g. engineer to order) and speculative (e.g. equipment offerings) developments. Industry aligned institutions interact by working with primary organisations to identify barriers to development and set out programmes to address these. These organisations have OWP specific products / services derived from, and part of, a wider range of interests and while the success of the industry is important, other industries also impact on them.
- **Tertiary:** These organisations are involved in the industry as a part of a wider range of interests (e.g. renewable energy in general). The involvement is more with 'outputs' from the industry (i.e. what the industry does for them) than with the inputs (i.e. what the industry needs from them). For example utilities are required to use carbon free electricity and OWP is a source of that; government departments need to meet policy goals and OWP has an impact; marine equipment suppliers can sell their products into the market (e.g. PPE, navigation aides etc.).

The types of organisation observed to be involved in offshore wind power generation are as follows:

- **Developers**: These can be either independent or part of an integrated utility. There are a number of differences between those 'pure play' developers, who are only involved in offshore wind, and utilities with an internal development function who may be involved in other power generation developments. Note that a number of the utilities develop in other markets e.g. EDPR, Vattenfall, Equinor.
- **Government regulators:** The various bodies responsible for administering the Contracts for Difference auctions, overseeing the Capacity Market, setting the Carbon Price etc.
- **The Crown Estate:** The Crown Estate is the owner and administrator of the seabed out to the 12 mile territorial limit. It is also the administrator of the seabed beyond this to the 200 nautical mile Renewable Energy Zone (REZ) limit (Energy Act, 2004). Separate bodies exist

for England & Wales and for Scotland. Leases for sites last 50 years, and the leaser pays an annual rent for the site.

- **Aligned institutions:** These are independent institutions who may or may not receive funding from government who have an interest in offshore renewable power production as well as other sectors. Examples are the Offshore Renewable Energy Catapult (ORE Catapult) which is heavily focussed on offshore wind, but also wave power and tidal stream; and the Carbon Trust which administers the offshore wind accelerator programme as well as being involved in a variety of other low carbon or carbon reduction initiatives worldwide.
- **Balance Of Plant equipment:** These are the organisations that can provide marine specific or function specific equipment to be used in the production or operation of offshore wind power. The products are not specific to the offshore wind industry. Examples are navigational aids, personal protective equipment, meteorological monitoring equipment etc.
- **Direct Services:** These are organisations providing consultancy and services to the industry such as engineering design, surveying, legal support, ports. The organisations have specific capabilities (skill and experience, specialist equipment) required for wind power but which can also be deployed for other purposes.
- **Finance companies:** These are the organisations that provide the external funds required to complete offshore wind developments. These may be commercial banks, specific banks (Green Investment Bank), investment funds (Greencoat) or pension backed funds (Copenhagen Investment Partners).
- **Foundation / Subsea producers:** These manufacturers produce the structures that sit on the seabed up to the wind tower. The organisations are also involved in other marine industries, typically Oil & Gas for whom they produce similar structures.
- **Government (policy & support):** These are divisions of government which set policy and provide mechanisms for support. These can either support or hinder the development of offshore wind power. Examples are the department for Business Enterprise and Industrial Strategy, Scottish Government, Scottish Enterprise.
- **Industry membership groups:** These organisations are set up to provide an industry-wide entity that can act on behalf of members. They include such organisations as Scottish Renewables, Wind Europe, Aberdeen Renewable Energy Group.

- **Institutions:** These are the not for profit organisations which can interact with the industry to support or hinder its development. They include Further and Higher Education establishments providing research or training, the 'Catapult' organisations within the UK and local Development Areas (e.g. Invest in Fife)
- **Utilities:** The customers of the output from offshore wind farms. Some of these organisations will also be developers.
- **Vessels:** These are organisations involved in both the build and the leasing of vessels. They are a special case of the **Direct Services** category and are included separately due to the industry concern over vessel availability in early days
- **Wind tower manufacturers:** These are the manufacturers of the column the turbines sit upon above the water level. As with the turbine manufacturers they service both offshore and onshore wind markets.
- **Wind turbine generator manufacturers:** These businesses manufacture both offshore and onshore wind turbines. At this time there are no 'offshore only' manufacturers, although the products are now specialised.

Table 4.1 below sets out how key groups of organisations within OWP fit these categories.

Table 4.1: OWP Industry Structure

Primary Organisations	**Secondary Organisations**	**Tertiary Organisations**
Developers	Wind turbine generator manufacturers	Utilities
Government regulators	Wind tower manufacturers	Government (policy & support)
The Crown Estate	Foundation producers	Finance companies
	Aligned institutions	Institutions
	Direct Services	Balance Of Plant equipment
	Vessels	Industry membership groups

At the time of writing the following organisations were the owners of the offshore wind power generation sites in the UK.

Table 4.2: Owners of operational wind farm sites (at December 2018)

Company	Number of sites	Capacity of Sites (MW)
Oersted (was Dong)	14	4263
Scottish Power Renewables	2	1103
Innogy (nPower Renewables)	3	1019
Vattenfall	6	1000
E.On	5	853
SSE	1	588
Airtricity	1	504
Green Investment Group (Macquarie)	3	464
Equinor (was Statoil)	2	432
EdF	2	104
Greencoat	1	6

5 of the ‘big 6’ utility companies are represented here. The absent company is Centrica which disposed of its assets to the Green Investment Bank which became the Green Investment Group on merger with Macquarie.

Table 4.3 below shows the currently active (at December 2018) developers in the UK offshore wind industry and splits them between Utilities based developers and stand-alone developers.

Table 4.3: Developers with active projects

Utilities	Sites in Dev.t	Independents	Sites in Dev.t
SSE	4	Hexicon AB	1
EDP Renewables UK	4	Inch Cape Offshore Limited (ICOL)	1
Innogy	2	Kincardine Offshore Wind Limited (KOWL)	1
Oersted (was Dong)	2	Mainstream	1
Scottish Power Renewables (part of Iberdrola)	2	Red Rock Power Ltd (SDIC buyout of RepsolNE)	1
Vattenfall	2		
EdF Renewables	1		

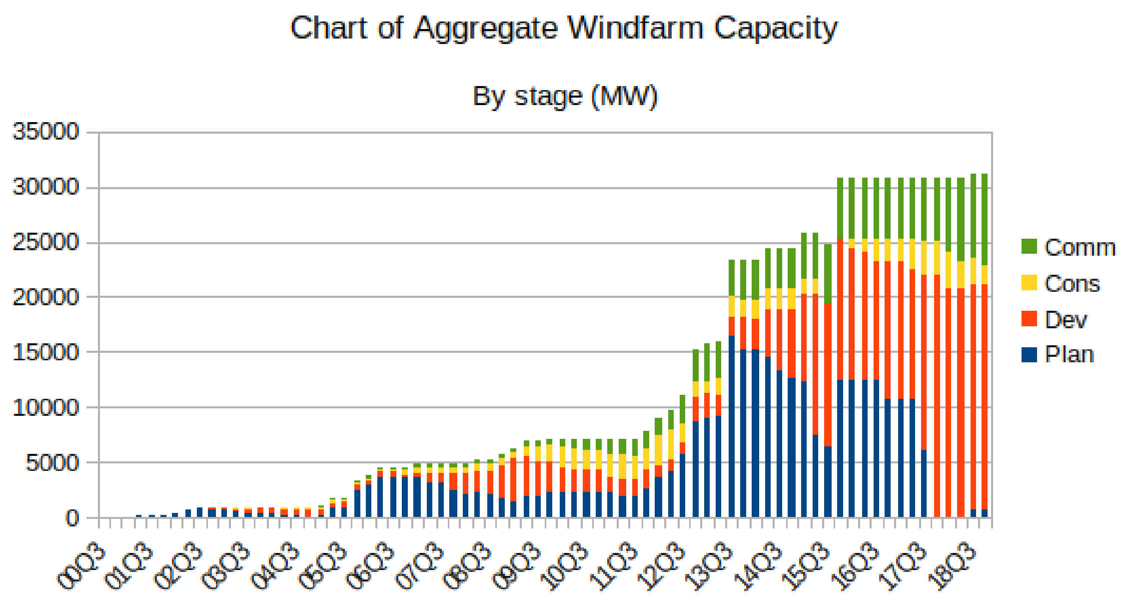
Table 4.4: Wind turbine manufacturers for projects operational and under construction

Manufacturer	# Sites	# Turbine	Capacity (MW)
Siemens (includes Siemens-Gamesa)	24	1600	7757
Vestas (includes MHI-Vestas)	14	851	2127
Senvion (was RePower)	2	118	467
2-B	1	2	12
CSIC	1	2	10
Samsung	1	1	7

The dominant position of Oersted as a developer and Siemens as a wind turbine manufacturer can be seen here.

4.3 Timeline of development

Figure 4.1: Timeline of Projects



(Comm = commissioned, Cons = under construction, Dev = in development, Plan = consent applied for)

4.3.1 Period pre-2000

No wind power was sited in UK waters before the millennium, however a number of projects were trialled in northern Europe as shown in table 4.5 below:

Table 4.5: Early offshore Wind Projects (Source WindEurope.org)

Location	**Date**	**Turbines**	**rating, kW**	**Output, MW**	**Water depth, m / Distance from shore, m**	**Foundation type**
Helgoland, DE	1989-95	1	1200	1.2	5 / 10	Gravity
Blekinge, SW	1990	1	220	0.22	6 / 250	Tripod
Vindeby, DK	1991	11	450	4.95	2-5 / 1500	Box caisson
Lely, NL	1994	4	500	2	5-10 / 800	Monopile
Tuno, DK	1995	10	500	5	3-5 /6 000	Box caisson
Dronten, NL	1996	19	600	11.4	Shallow / 50	Monopile
Bockstigen, SW	1998	5	550	2.75	6 / 4000	Monopile

These early sites are notable for being in relatively shallow waters (less than 6 metres depth below mean sea level, many were exposed at low tide) and close to shore, the furthest being less than 4km offshore.

Vindeby in Denmark is generally considered to be the first offshore wind farm in the world (Source WindEurope.org). Its 11 wind turbines generate about half the power of a single 2018 turbine (e.g. the MHI Vestas V164/8.8 installed at the European Offshore Wind Development Centre generates 8.8 MW). The Dronten site in the Netherlands has ‘offshore’ wind turbines that are accessed directly from shore by walkways from the breakwater.

In the UK, 2 applications for offshore wind farms were made under the auspices of the the Non Fossil Fuel Obligation (NFFO) in 1996. These were for sites at Gunfleet Sands in Essex and Blyth in Northumberland.

4.3.2 Period 2000 – 2005

The first offshore wind generation established in the UK was commissioned late in 2000 at Blyth harbour in Northumberland. This project placed 2 turbines in the sea approximately 1km from the shore.

Also in 2000, The Crown Estates, in their capacity as owner and administrator of the seabed out to the 12 mile territorial limit, launched an initial Development Round (source: The Crown Estate website) to provide structure to the development of offshore wind power sites. The earlier applications at Gunfleet Sands and Blyth were added to the Round 1 structure.

Round 1 sites were intended for demonstration scale projects with a limit of 30 turbines in each site. The location of sites was largely left to developers.

All future UK offshore wind development follow this pattern of leasing rounds run by The Crown Estates with a particular focus for each of the rounds.

The first development round awarded leases to 18 sites in 13 locations in April 2001, with a combined generating capacity of 1.7GW (see table 4.6 below).

Table 4.6: Round 1 lease awards

Name	Location	MW Capacity	Developer
North Hoyle	North Wales	60	npower renewables
Scroby Sands	East of England	60	E.ON UK Renewables
Kentish Flats	Thames Estuary	90	Vattenfall
Barrow	North West England	90	Centrica/DONG Energy
Gunfleet Sands I	Thames Estuary	108	DONG Energy
Lynn/Inner Dowsing (2 sites)	Greater Wash	194.4	Centrica
Rhyl Flats	North Wales	90	npower renewables
Burbo Bank	North West England	90	DONG Energy
Robin Rigg (2 sites)	North West England (Scottish Waters)	180	E.ON UK Renewables
Teesside	Yorkshire & Humber	90	EDF
Ormonde	North West	150	Vattenfall
Cromer	East of England	108	EDF
Cirrus Shell Flat Array (3 sites)	North West England	284	Celtpower
Scarweather Sands	South Wales	108	E.On / Energie 2

The first planning applications for these sites went in in 2001 (Scroby Sands and North Hoyle) with the last applications happening in 2005 (Ormonde).

The UK Government carried out a Strategic Environmental Assessment (SEA) between November 2002 and February 2003. This was used to identify 3 areas suitable for offshore wind power developments at commercial scale – the Thames Estuary, the Greater Wash and the North West (of England).

The Crown Estate followed up Round 1 leasing with Development Round 2 in July 2002 bringing in 41 bids (source The Crown Estate website). This Round's focus was to allow commercial scale production of offshore wind power and was supported by the previously reported SEA.

Leases were awarded to 15 projects (17 sites e.g. London Array I and II are separate sites) in December 2003 as shown in Table 4.7 below

Table 4.7: Round 2 lease awards

Name	**Location**	**MW capacity**	**Developer**
Docking Shoal	Greater Wash	500	Centrica
Race Bank	Greater Wash	620	Centrica
Sheringham Shoal	East of England	315	Statoil Hydro/Statkraft
Humber Gateway	Yorkshire & Humber	300	E.on
Triton Knoll	Greater Wash	1,200	npower renewables
Lincs	Greater Wash	270	Centrica
Westermost Rough	Greater Wash	240	DONG Energy
Dudgeon	Greater Wash	560	Warwick Energy
Greater Gabbard	Thames Estuary	504	SSE Airtricity/Fluor
Gunfleet Sands II	Thames Estuary	64.8	DONG Energy
London Array 1	Thames Estuary	630	DONG Energy / E.ON UK Renewables/ Masdar
London Array II	Thames Estuary	370	DONG Energy / E.ON UK Renewables/ Masdar
Thanet	Thames Estuary	300	Vattenfall
Walney I	North West	183.6	DONG Energy
Walney II	North West	183.6	DONG Energy
Gwynt y Mor	North Wales	750	npower renewables
West of Duddon Sands	North West	500	ScottishPower / DONG Energy

The first site operational from Round 1 was at North Hoyle in Wales, with a capacity of 60 MW from 30 2MW machines. The site became operational late in 2003. This was followed quickly in March 2004 by Scroby Sands wind farm with the same nominal capacity and number of turbines.

No planning applications for sites were submitted in 2004. Two Round 1 sites still had not come forward for planning consent at this time (Teeside and Ormonde).

By September 2005 the UK's third offshore wind farm Kentish Flats was operational. At the time of its commissioning it was the largest capacity such wind farm at 90MW from 30 turbines. The capacity increase coming from the size of the individual units, the number of units matching the previously commissioned sites as per the requirements of Round 1 leasing.

At the end of 2005 the last planning submission for a Round 1 site (Ormonde) had been submitted and the first four Round 2 sites had been put forward for consent.

4.3.3 Period 2006 – 2010

Early 2006 saw the planning application for the Beatrice demonstration project. This consisted of two 5MW turbines sited in deeper (>40m) water, 12 miles offshore from Caithness. These turbines were not grid connected but exported their power to a nearby oil and gas platform of the same name. The project aim was to show that the largest wind turbines could be installed and operated further offshore than demonstrated in Round 1 sites.

The only site to be commissioned in 2006 was Barrow – a round 1 site.

2007 also saw a single Round 1 site commissioned (Burbo Bank), along with the Beatrice demonstrator.

The first offshore wind farm application to be refused (London Array Phase 1) was passed after appeal in 2007 after a reduction in the number of turbines to 175 to reduce the impact on local bird life.

By 2008 the rate of installations was accelerating with 2 Round 1 sites commissioned, totalling 194 MW – more than double any previous year. More round 2 sites were being submitted for approval with a total of 12 sites from the 17 submitting by year end.

The Scottish Government requested the Crown estate run a leasing round for Scottish Territorial Waters (STW) to promote the development of the supply-chain in Scotland. This was launched in May 2008 with 9 companies being awarded leases for 10 sites within Scottish Territorial Waters in February 2009.

Table 4.8: Scottish Territorial Waters lease awards

Name	Capacity (MW)	
Beatrice	588	SSE Renewables / SeaEnergy
Neart na Gaoithe	450	Mainstream
Inch Cape	784	Repsol / EDP Renováveis
Islay	690	SSE Renewables
Argyll Array	1800	Scottish Power Renewables
Hywind Scotland Pilot Park	30	Statoil

There was a further acceleration of commissioned sites in 2009, with a total of 346 MW operating over 4 sites including the first Round 2 site to be operational (Gunfleet Sands 2).

By the end of 2009 15 of the 17 Round 2 sites had submitted planning applications. It was recognised [27/9/09 Crown Estates press release (Wayback machine)] that there would be a significant gap in projects before Round 3 installations kicked in – the Round 3 leasing process ran throughout 2009 with the winning bids notified in 2010. The Crown Estates allowed developers to propose extensions to Round 1 and 2 sites to help fill the expected gap in projects and to smooth the run of projects.

The Crown Estates also worked with Round 1 & 2 lease holders to harmonise lease conditions. Some Round 1 sites had 25 year leases and some Round 2 had 40 year leases. All were extended to 50 years so that a common lease period applied across all rounds.

2009 also saw the introduction of banding to the Renewables Obligation Certificate scheme. Rather than being a single mechanism, different technologies became eligible for different levels of ROCs (Ofgem, 2014). Offshore wind Generation is given 2 ROCs in comparison to Onshore Wind at 1.

Round 3 differed again from the earlier rounds in that it offered sea-bed zones, backed up by Strategic Environmental Assessment carried out by the UK government, in which appropriate sites could be developed. The scale of these zones was substantially greater than seen previously, with scales of projects in the GW range. A developer could develop a number of wind farms within these zones.

2010 saw the fourth record year for commissioned capacity in a row, with 390 MW coming on stream from one Round 1 and one Round 2 site.

2010 also saw the Leasing Round 3 areas awarded with 10 consortia of developers gaining exclusivity to 9 areas for project development (see table 4.9 below).

Table 4.9: Round 3 lease awards

Name	Location	MW capacity	Developer
Moray Firth	North Scotland	1000	Repsol / EDP Renováveis
Firth of Forth	East Scotland	3465	SeaGreen Wind energy Ltd (SSE Renewables, Fluor)
Dogger Bank	East England	4800	Forewind Consortia (SSE Renewables, RWE Npower Renewables, Statoil and Statkraft)
Hornsea 1 (Heron & Njord) Hornsea 2 (Optimus Wind & Breesea)	East England	1200 1800	DONG Energy Smart Wind Consortia (Mainstream Renewable Power, Siemens Project Ventures)
East Anglia ONE East Anglia 2/3	East England	7200	East Anglia Offshore Wind Ltd (Scottish Power Renewables)
Rampion	South England	400	E.On Climate and Renewables
Navitus Bay	South England	970	Eneco New Energy and EDF
Celtic Array	West England	4200	Centrica & DONG Energy
Atlantic Array	West Scotland	1200	RWE Npower Renewables

In 2010, the UK general election led to a change of government from Labour to Liberal Democrats / Conservative coalition. Part of the programme for government of the coalition was the explicit goal to expand renewable generation (to a target of 30% by 2020) and to maintain the ROC mechanism (UKGov 2010).

Towards the end of 2010 a consultation was launched on energy market reform that introduced the idea of a feed in tariff and contracts for difference support mechanism to replace the ROC mechanism (UKGov 2010).

No planning applications for offshore wind farms in 2010, the first year since 2004 that this had happened.

4.3.4 2011

A single site was commissioned in 2011 – Walney I. This was a Round 2 site with 184 MW capacity. This marked a significant drop in annual capacity commissioned for the first time. This was more related to longer construction time for the larger round 2 wind farms than any reduction in activity levels in the industry.

Planning submissions were put in for 3 sites, European Offshore Wind Development Centre in Aberdeen Bay (a demonstration round site), London Array II (Round 2 site) and Galloper (a Round 2 extension site - extending Greater Gabbard). Consents were awarded to 3 sites, Humber Gateway A (from Round 2), Levenmouth (a Round 3 demonstration site) and Westermost Rough (Round 2) totalling totalling 436MW planned capacity.

Construction started on 2 sites, London Array I (Round 2 site) and Walney II (Round 2 site) totalling 814 MW capacity (equivalent to 50% of the installed capacity at the time).

The government launched a consultation on ROC banding to apply for the period from 2013 to 31 March 2017. This would maintain the ROC band for offshore wind until 2014, then reduce it leading up to the end of the scheme in 2017.

A separate white paper was published setting out the proposed energy market reform that would introduce Contracts for Difference (CfD) in place of ROCs.

4.3.5 2012

2012 saw 1.2 GW of capacity commissioned offshore from 4 separate projects (Ormonde from Round 1, Greater Gabbard, Sheringham Shoal and Walney II – all Round 2). This represented a 75% increase in offshore wind capacity and was a record year for commissioning to this point.

Planning submissions were made for 11 sites totalling 4.7 GW of capacity. These came from Round 2 (1 application), Round 2 extension (1 application), demonstration sites (1 application), Scottish Territorial Water round (2 applications) and Round 3 (6 applications). This marked a significant growth in the number of applications (more than the previous 5 years together) and was a record for capacity put forward for consent. Consents were awarded to 4 sites, Gunfleet Sands Extension (a demonstration site), Race Bank Phases 1 and 2 (Round 2 site) and Dudgeon East (Round 2 site) – a total of 987 MW capacity, more than double the previous years total of consents.

Construction began on 3 sites totalling 650MW capacity; Teeside Offshore Wind Farm (Round 1 – the last Round 1 site to begin construction), Gunfleet Sands Extension (a demonstration site), Gwynt y Mor (Round 2 site – the eighth to be started, marking half of the Round 2 sites under construction by this date).

The government published a draft of the CfD mechanism as part of its policy paper *'Electricity market reform: policy overview'* (UKGov, 2012). This paper identifies the intention for pricing for renewable technologies to be based on competitive measures from 2017.

CfD would last for 15 years in comparison to 20 years support for ROCs.

4.3.6 2013

974 MW of new capacity was commissioned in 2013. This was a slight reduction on the previous year. The capacity came from 4 sites, Gunfleet Sands Extension (a demonstration site), Lincolnshire (Round 2) , London Array One (Round 2), Teeside (the last Round 1 site).

Applications were made for 7 sites although one was withdrawn before the end of 2013 (Atlantic Array). Despite a smaller number of applications, the total capacity going forward for planning was 5.7GW, a 20% increase on the previous record year. This excludes the capacity of the withdrawn site (1.2GW). During the year planning consent was granted for 5 sites totalling 1.4GW capacity. These sites were a mixture of Round 2 (1 site), Round 2 extension (2 sites), Scottish Territorial waters (1 site) and demonstration sites (1 off).

3 sites began construction in 2013, 2 Round 2 sites (West of Duddon Sands, Humber Gateway A) and a single Round 3 demonstration site at Levenmouth. These totalled 615MW, the Round 3 demonstration site being only a single 7MW turbine.

The Energy Market Reform activity by the UK government led to the Energy Act 2013 which passed into statute at the end of that year. This act sets out the both the Contracts for Difference mechanism for subsidising non-carbon generation and the Capacity Market mechanism for ensuring security of supply. Together these represent a significant change in the operation of the UK's electricity generating and supply market.

Although the Act set out the CfD mechanism no indication was given on the expected 'Strike Price' that would be sought in the first CfD auction (due in 2015).

As a transition arrangement from ROC to CfD, the government announced a Final Investment Decision enabling CfD process that would apply to projects submitted before 1 July 2013. This arrangement supported 5 offshore wind projects with a strike price of £140 / MWhr (announced in 2014).

4.3.7 2014

2014 marked a significant downturn in commissioning of sites with only a single commercial scale project coming on stream (West of Duddon Sands, a round 2 site). The Levenmouth demonstrator, a single 7MW turbine, also came on stream in this year.

The reduced commissioning activity was also mirrored in the number of applications made for new sites, with 3 Round 3 sites being put forward, Dogger Bank Teeside A, Dogger Bank Teeside B and Navitus Bay. These site had a combined planned capacity of 3.4 GW.

Far more activity was visible in the granted applications with a total of 9 sites gaining consents (Rampion Offshore Wind Farm (Hastings Zone), Burbo Bank Extension (Burbo Bank 2), Walney 3, Beatrice, Hornsea Project One - Heron & Njord, East Anglia 1 (EA 1), Moray East (3 sites)), 1 from Scottish Territorial water round, 2 Round 2 extensions and 6 Round 3 applications. The sites totalled 4.8GW of projected capacity.

Construction was commenced on just 2 projects – Westermost Rough A, a Round 2 project, and Kentish Flats 2, a Round 2 extension project. These projects provide 260MW of additional capacity.

5 offshore wind projects were given contracts under the FID enabling scheme – Beatrice (Scottish Territorial Waters), Burbo bank extension (Round 2 extension), Dudgeon (Round 2), Hornsea 1 (Round 3), Walney extension (Round 2 extension).

CfD allocation process for the 2015 allocation (Allocation Round 1) got underway with notes and guidance to generators being published by the UK Government. The Budget Allocation Notice released in October 2014 identified the Strike Price for less-established technologies (including Offshore Wind Power) at £155 / MWhr initially, falling to £140 / MWhr for 2018/19. The budget notice also identified the total budget size for each year.

4.3.8 2015

In contrast to the downturn of commissioning of new offshore wind power in 2014, 2015 had a near record levels of commissioned wind power with 3 Round 2 wind farms (Westermost Rough, Humber Gateway A and Gwynt y Mor) and a Round 2 extension site (Kentish Flats 2) coming on stream. These projects totalled 1.1 GW just less than the record year of 2012.

Applications were submitted for 4 projects totalling 2.6 GW. The majority of this capacity came from 2 Round 3 sites (Hornsea 2 and East Anglia 3). The other 2 sites were for demonstration projects (Hywind 2 – a floating wind demonstrator – and Methil an extension of the Levenmouth demonstration site to demonstrate a long-life 2 blade wind turbine design). Consents were granted for 4 projects, 3 Round 3 (Dogger Bank Creyke Beck A & B, Dogger Bank Teeside B (Sofia) and Dogger Bank Teeside A) and Hywind 2 (the floating wind demonstrator identified earlier). These projects had a combined planned capacity of 4.8GW

No construction of wind farms was commenced in 2015 – the first year this was true since 2003 when the first Round 1 sites commenced build. A hiatus in construction starts was expected between Round 2 and Round 3 build out. However at this time a number of Round 2, Round 2 extension and Scottish Territorial Waters projects still had not commenced construction.

2015 saw the completion of the first CfD allocation round. 2 offshore wind projects were successful, East Anglia 1 and Neart Na Gaoithe, with strike prices of £119.89 / MWhr and £114.49 / MWhr respectively, covering a capacity of 1.3GW. The 15 onshore wind projects in the same round had an average strike price of £82. This covered 0.75 GW of capacity.

In May there was a change of government to a Conservative majority government. Manifesto commitments included (Conservative Party, 2015);

- *a significant expansion in new nuclear and gas; backing good-value green energy; and pushing for more new investment in UK energy sources*
- *we will end any new public subsidy for them* [onshore wind farms] *and change the law so that local people have the final say on wind farm applications*
- *we will continue to support the UK Climate Change Act. We will cut emissions as cost-effectively as possible, and will not support additional distorting and expensive power sector targets*

In June the government set out its intention to end subsidies for onshore wind. The ROC regime would close to onshore wind in 2016, a year ahead of plan, with exceptions being made for certain projects which had significantly progressed in development at the time of the announcement.

4.3.9 2016

There was no new offshore wind power commissioned in 2016. This was inevitable given no new construction commencing in 2015.

There were also few applications for planning consent in 2016 with only 2 floating demonstration sites (Kincardine Offshore Windfarm and Douneray Tri-floating Wind) coming forward. Planning consent was granted a single Round 3 site (Hornsea 2 – 1.4GW) as well as the Methil 2-blade demonstrator site (12MW).

The year did see construction of projects recommence with 6 sites including the first Round 3 site and the first sites to gain CfD contracts – Rampion (Round 3), Dudgeon East (Round 2), Burbo Bank extension (Round 2 extension), Race Bank 1 & 2 (Round 2) and Galloper (Round 2 extension – of Greater Gabbard) . The sites totalled 2.0 GW of capacity.

The government closed the Department for Energy and Climate Change (DECC) which had been the body managing the energy market and created a new department for Business, Energy and Industrial Strategy (BEIS) which incorporated these responsibilities along with those from the department for Business Innovation & Skills (BIS).

4.3.10 2017

After a very downbeat year in 2016 activity in offshore wind again picked up with 5 projects coming on stream. These were Burbo Bank extension (Round 2 extension), Race Bank 1 (Round 2), Dudgeon east (Round 2), Hywind 2 (floating wind demonstrator) and Rampion (the first large scale Round 3 site operational). These sites totalled 1.4 GW of capacity a record level of commissioning, and more than the previous 3 years put together.

There were no applications for new offshore wind projects in 2017, reflecting the status where all sites leased under the various rounds had projects submitted for planning permission. Additional projects can still be developed within Round 3 lease areas however.

Consents were granted to 7 offshore wind projects including the final go ahead for NNG and Inch Cape which had been under a planning appeal process since 2014.

Construction commenced on 4 sites, the Blyth Offshore Wind Test Site (a demonstration site), Beatrice (Scottish Territorial Waters), Walney 3 (Round 2 extension) and the Hywind Scotland Pilot Park (Hywind 2) Demonstrator (A Scottish Territorial Waters round site). These sites totalled 1.3 GW of capacity.

Beatrice and Walney 3 were the major contributors (588 MW and 660 MW capacity respectively) and these sites will operate with CfD support.

The year also saw the launch and completion of CfD Allocation Round 2. Three offshore wind projects won contracts totalling 3.2GW of capacity. This covered approximately 95% of all the generating capacity which gained a CfD.

The Crown Estates announced an intention to hold a fourth leasing round for offshore wind development sites in 2019 (Crown Estate, 2018)

4.3.11 2018

5 sites became operational in 2018 (up to 29th September). These were the European Offshore Wind Deployment Centre (EOWDC) (Demonstration site), Blyth Offshore Wind Test Site (Demonstration site), Galloper Wind Farm (Round 2 extension), Walney 3 (Round 2 extension) and Race Bank 2 (Round 2). The sites have a combined generating capacity of 1.4 GW and the total just exceeds the previous year's record for new capacity commissioned.

Planning applications were submitted 5 sites also. These were Neart na Gaoithe (this is a resubmission of the STW round after the lengthy appeal process to take account of improved turbine technology to reduce the number of turbines required), Hornsea Project Three (Round 3), Thanet (Round 2 extension), The East Anglia Array - Norfolk Vanguard (Round 3), Moray Firth 2 (West) (Round 3). These represent a potential capacity of 4.5GW (an additional 4GW if the NNG capacity is discounted due to prior approval).

No projects gained planning consent in 2018, reflecting the lack of submissions in 2017.

Construction began on 3 sites in 2018, European Offshore Wind Deployment Centre (EOWDC) (Demonstration site), East Anglia 1 (Round 3) and Hornsea Project One - Heron & Njord (Round 3). The EOWDC also completed its construction within the year as a relatively small development of 11 turbines. The larger round 3 sites will have a combined capacity of 1.9 GW when completed.

At the time of writing 7.9GW was in commission with another 2 GW under construction. A further 4 GW of capacity has a CfD and can be expected to start construction. A realistic target for capacity in 2020 is therefore 14GW.

4.3.12 Looking forward

Late in 2017 a third CfD Allocation Round was announced for Spring 2019 along with the intent to continue biannual applications through the 2020's. A draft budget for the third allocation round was released in November 2018.

This and future rounds are expected to support the development of 2GW of new capacity annually up to 2030 (i.e. an additional 10 GW of capacity). This will potentially double the capacity of offshore wind in this timescale.

At the time of writing, the UK government has committed to achieving 30GW of offshore wind capacity by 2030. This represents completing the development of all the projects currently with planning consent.

The next section builds upon this history of the industry by looking at the constituent sub-systems that can be considered to describe it.

4.4 Industry Human Activity (Sub-)Systems

Systems can be represented in many ways. They can be shown as a 'black box' where all detail is summarised as inputs and outputs (IDEF0 top level node is an example) or as a more detailed model where some indication of internal structure and activity is given; this may be using a formal syntax such as a decomposed IDEF0 node or a Systems Dynamics model, or without any predefined structure as in Checkland's 'Rich Picture' models.

The logic for such decomposed models (see www.idef.org for more detail) is that it highlights that a system is made up of connected nodes, and that these nodes are frequently systems in themselves. The level of decomposition should ensure that the nodes 'make sense' as stand alone elements and that the interaction between nodes provides some understanding of system behaviour.

In IDEF0 functional modelling, the element decomposition is guided by function and a range of sub-elements to use is suggested (3 to 6. A full explanation of the syntax of IDEF0 modelling can be found at www.idef.com). In Checkland's Soft System Methodology the decomposition guidance is to look at 'human activity systems' (Checkland 1981 pp 110). In System Dynamics the decomposition is into process elements that provide some form of transformation of flows into stocks (Meadows 2008).

Each of these approaches will lead to a different model of the system, and so the selection of nodes (or in this case sub-systems) is a core decision in any system analysis. It is important to pay attention to George Box's aphorism - *'All models are wrong, but some are useful',* first put in print in *'Science and Statistics'* (Box, 1976). The primary concern is to avoid trying to improve the 'rightness' of a model by adding detail, and instead to follow William of Ockham's law of parsimony and look for the minimum detail necessary to describe the system (George Box refers to 'worrying selectively').

To arrive at the most 'useful' model of the offshore wind power industry a number of alternatives were considered as follows;

- **Individual supply chains:** In established industries such as automotive / retail (supermarkets) / consumer electronics it is the consumer facing organisation (OEM) and its supply chain which is the defining characteristic e.g. VAG and its tier one suppliers v. toyota and its tier one suppliers, Tesco and its suppliers v. Sainsburys and its suppliers, Apple and its supply base v. Samsung
- **Projects:** This form would suggest that Offshore Wind Power is not an industry, but is only a series of projects undertaken to fulfil a specific need.
- **Activity based model:** Here the focus is on the distinct activities that significant portions of the industry participants get involved with.

The first approach could not be made to fit as there were significant numbers of customer facing organisations (developers in this case) and only a few tier one suppliers (e.g. of wind turbine generators). Attempting to describe discrete sub-systems leads to the (incorrect) impression that offshore wind power is in fact a sub-system of Siemens.

In fact this pattern is typical of a Complex Product or Service industry (CoPS) where technology integrators work with technology providers to provide tailored (engineered) solutions to a small number of customers (usually corporate bodies and governments rather than individual consumers) (see Hobday, 1998 for an overview of CoPS industry).

A projects based model is arguable and some criticism of the technology suggests this view was held by some observers (e.g. "*£250bn wind power industry could be the greatest scam of our age*" Daily Mail Online [WWW Document], n.d. URL https://www.dailymail.co.uk/news/article-1361316/250bn-wind-power-industry-greatest-scam-age.html (accessed 4.16.19), "*The windfarm delusion*" The Spectator [WWW Document], n.d. URL https://www.spectator.co.uk/2012/03/the-winds-of-change/ (accessed 4.16.19)). In a project based model the participants would come together to achieve a single (economic) goal (e.g. produce a single wind farm that generates a good return on the invested resources) with no view to on-going activity (in this case, further wind farm developments). This argument can be countered by the large number of individual projects undertaken (over 50 applied for in UK waters at the time of writing, with 36 operational), the significant number of developers involved in several projects (Oersted, Vattenfal, SPR, etc.) and the effort put in by the involved organisations to establish Offshore Wind Power as an ongoing industry (trade shows, government lobbying, public engagement). The case findings section later will return to this argument as it is essentially questions whether the observed activity constitutes an industry.

The third option of an activity based model was selected. This is deemed to better fit the observed pattern of interactions (see section 4.5 reviewing the OWP Supply Chain conference) than the alternatives given above, without being overly prescriptive of the activities and their nature (e.g. in the way that a Systems Dynamics or Living Systems Theory model would be). Again this will be explored further later when reviewing the utility of a systems model of an industry.

The selection of the sub-systems shown below came from the observation of the supply-chain conference and was validated via the semi-structured interviews of industry participants.

4.4.1 The Planning Sub-system

In the United Kingdom the sea bed out to the 12 Nautical Mile limit is owned by The Crown Estate. In common with other countries, the UK also claims a 200 mile exclusive economic zone (EEZ) under the UN Convention on the law of the sea (UNCLOS). The UK government has given the Crown Estates the administrative role for all renewable energy development in this area – designated as the renewables energy zone (REZ). The Crown Estates is therefore in a position to manage leasing for all offshore wind developments (as well as tidal stream, wave power etc.).

Sites for development have been leased via a series of rounds as follows:

Table 4.10: Leasing rounds and rationale

Round	Date	Over-riding intention
1	2001	Demonstration of commercial feasibility. Sites are to be no larger than 30 turbines. Developers can suggest locations.
2	2003	Commercial scale sites within pre-determined areas. SEA based *(needs more detail)*
STW	2008	Sites within the 12NM limit in Scottish waters. More challenging conditions (deeper water, rockier foundations??)
3	2010	Large scale commercial zones. Potential for multiple projects. (*The big prize)*

Leasing a site does not license or consent a developer to build an offshore windfarm, this is covered by separate legislation. At the start of the production of Offshore Wind farms in 2000 consenting of developments was governed by Section 36 of the Electricity Act 1989. This act was the instrument that started the privatisation of electricity supply within the UK.

Section 36 consent was required for all electricity generating developments over a stipulated scale (see DECC, 2007 for more detail). Any such development was also required to have planning permission under the Town and Country Planning Act 1990. This was normally dealt with via Section 90(2) of the Town and Country Planning Act 1990 whereby the Secretary of State can provide the planning permission for the development, rather than the applicant having to separately apply to the local planning authority for it – known a ‘deemed consent’.

The act applies to England and Wales, and similar arrangements are in place for Northern Ireland and Scotland. In the later cases, deemed consent is applied for via the appropriate minister.

It is worth noting that the Electricity Act 1989 has a split for consenting requirements for sites under 100MW offshore (a similar split at 50 MW applies onshore) – most Round 2 sites were below this threshold, all round 3 sites are over this threshold. Below the threshold the provisions of the Town and Country Planning Act 1990 are applied.

The ‘Section 36’ planning process was ‘dis-applied’ by the Planning Act 2008 (except for any applications underway at that time) and replaced with the provisions of Nationally Significant Infrastructure Plans (NSIP) as managed by the Planning Inspectorate in England and Wales (PINS). In the current regime, developments below 100MW are responsibility of the Marine Management Organisation (MMO) in England and Wales.

In Scotland a single statutory body, Marine Scotland, was set up to ensure a coordinated approach to the sustainable development of marine resources around Scotland. These include fisheries, marine energy and other seabed resources. The organisation came into being in 2009.

This was followed by the Marine (Scotland) Act 2010 which has the explicit goals of:

- **Marine planning**: a new statutory marine planning system to sustainably manage the increasing, and often conflicting, demands on our seas
- **Marine licensing**: a simpler licensing system, minimising the number of licences required for development in the marine environment to cut bureaucracy and encourage economic investment

In Scotland, the Marine Scotland Licencing and Operations Team was set up to provide a ‘one-stop’ shop for all licencing and consenting requirements (see ScotGov, 2018). A similar Consents Services Unit was set up in the Planning Inspectorate (The planning Inspectorate, 2015) for all non-planning consents in England & Wales in 2013.

Sites with existing S36 consents which are seeking variation e.g. site extension, work via BEIS (not PINS) for this. Section 36 plans in Scotland apply to Scottish Ministers.

It can be seen that the planning environment is highly technical and has a number of complicated requirements for developers. The guidance documents indicate the benefit of having a clear Environmental Impact Assessment (EIA) for the proposed wind farm site and the likely contents of that EIA e.g. bird surveys, benthic studies etc. These are on top of the location studies required to design the wind farm (meteorology, oceanographic, seabed geology etc.). This complexity is only increased by the requirements for onshore planning consent for power lines and sub-stations and the need for approval of a grid connection. The planning system has also changed in all the UK territories during the development of offshore wind power industry to date.

This complication can be set aside to some extent as, at an industry level, the key concerns are relatively straight forward:

- Do sites gain consent?
- How long does it take to gain consent?
- How predictable is the timescale for consenting?

Table 4.11 below shows how planning performed over the 3 leasing rounds undertaken for OWP

(Source: BEIS, 2018)

Table 4.11: Planning outcomes for Projects by Leasing Round and Jurisdiction

Round & Jurisdiction	Round 1		Round 2		STW	Round 3		Total
	E&W	Sco	E&W	Sco.	Sco.	E&W	Sco.	
Applications	**14**	**2**	**17**	**0**	**6**	**9**	**2**	**51**
Refused	2		1		2	1		4
Appeals	1				2			2
Withdrawn	2		1		2	2		8
Successful (including appeals)	**11**	**2**	**15**		**4**	**6**	**2**	**40**
Average time in approval (days)	629	367	742	n/a	1018	536	959	

Note that a single site in Round One was refused and a revised proposal was passed after appeal. Two Scottish Territorial Waters (STW) projects (Neart Na Gaoithe and Inch Cape) that were rejected as part of a judicial review were also passed after appeal. Due to the time taken these STW site plans have been revised to take account of improved technology.

It can be seen that overall approximately 80% of sites have gained approval, with the largest fall out being sites that were withdrawn by developers. On a strict measure of refused applications, only 4% of projects were stopped at the planning stage (2 out of 51 where no appeal was granted and/or no appeal sought).

In terms of the average time taken for planning a great deal of variation can be seen. The limited number of Scottish projects makes statistical analysis by round inappropriate, however the larger number in England and Wales does allow for some analysis by round.

In the England & Wales sites the Round 2 applications are clearly normally distributed (see probability plot below), those for Round 1 appear to be 2 separate distributions (one for 'short' decisions and one for 'long' decisions) and the Round 3 sites are approximately normally distributed also.

This is shown in figures 4.2a-c below.

Figure 4.2a: Round 1 Planning Timeline (Normality Plot)

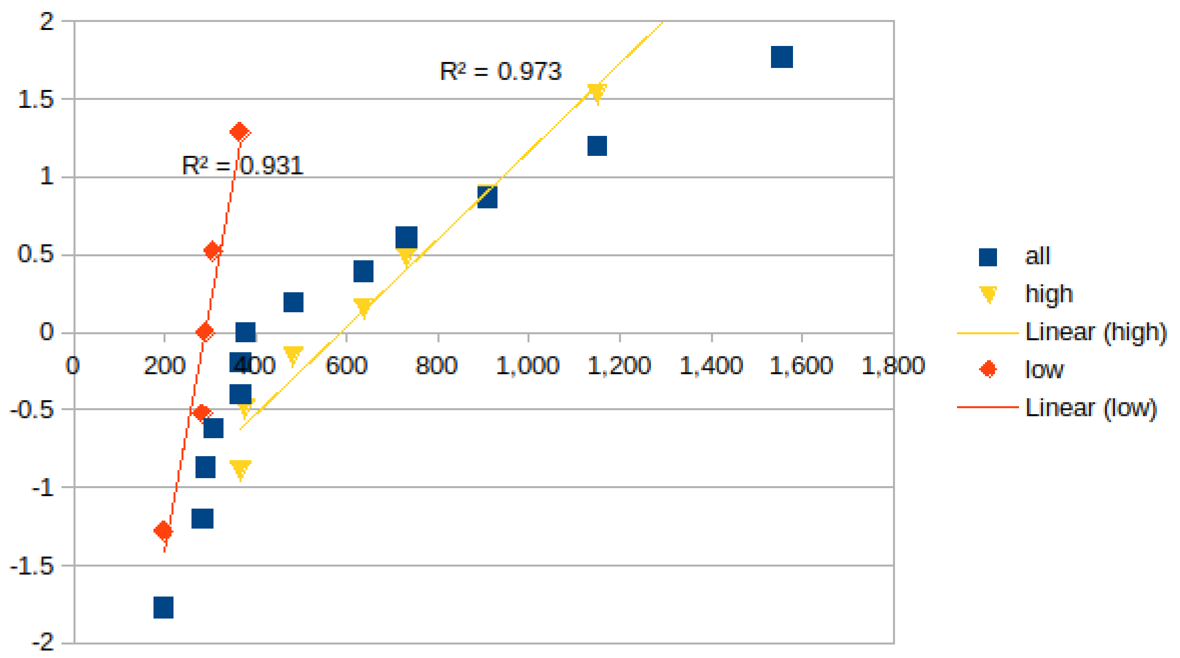


Figure 4.2b: Round 2 Planning timeline (Normality Plot)

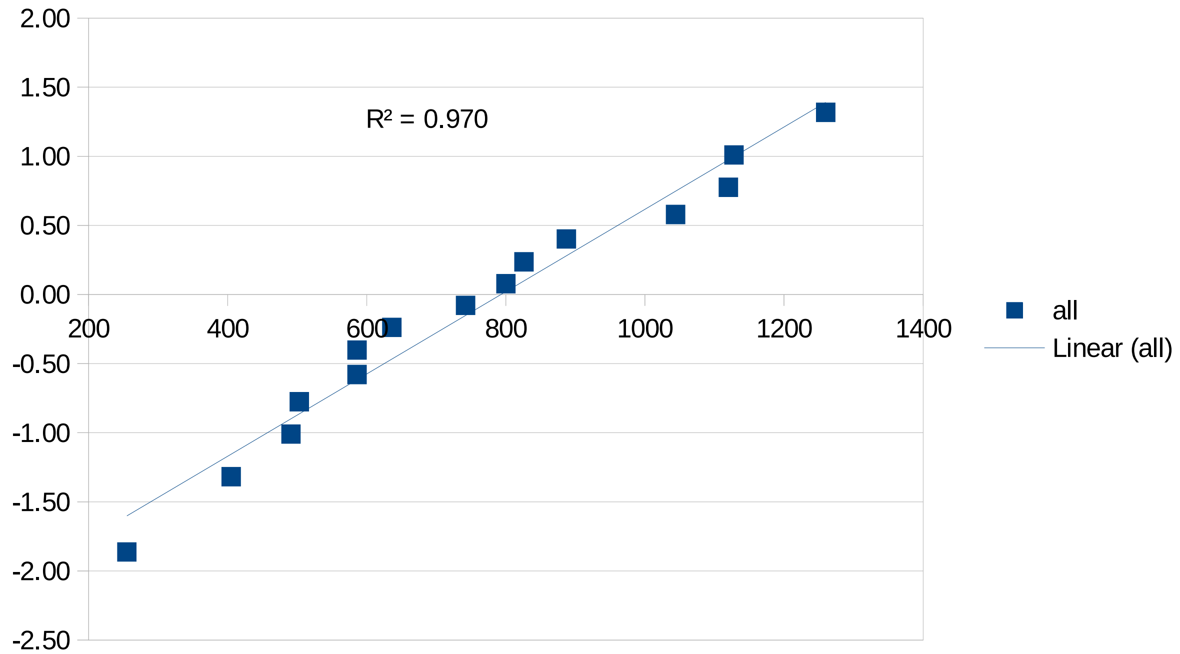
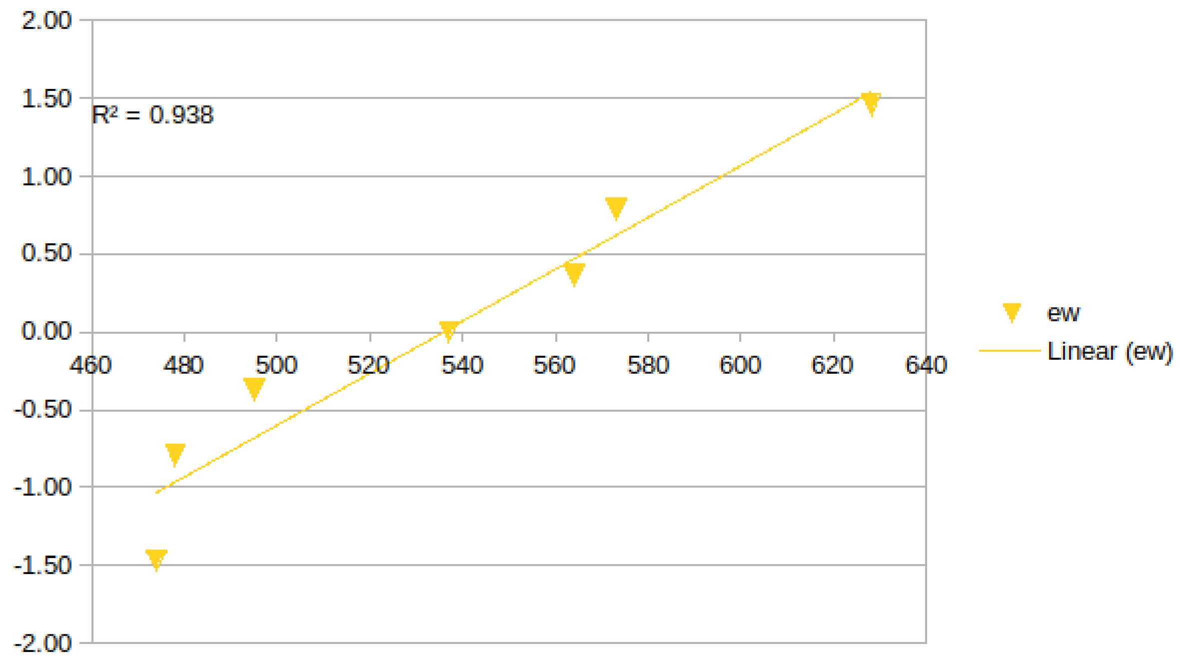


Figure 4.2c: Round 3 Planning Timeline (Normality Plot)



As a result of this it is possible and appropriate to give some indication of confidence intervals for the planning lead-time in England and Wales as shown in Table 4.12 below.

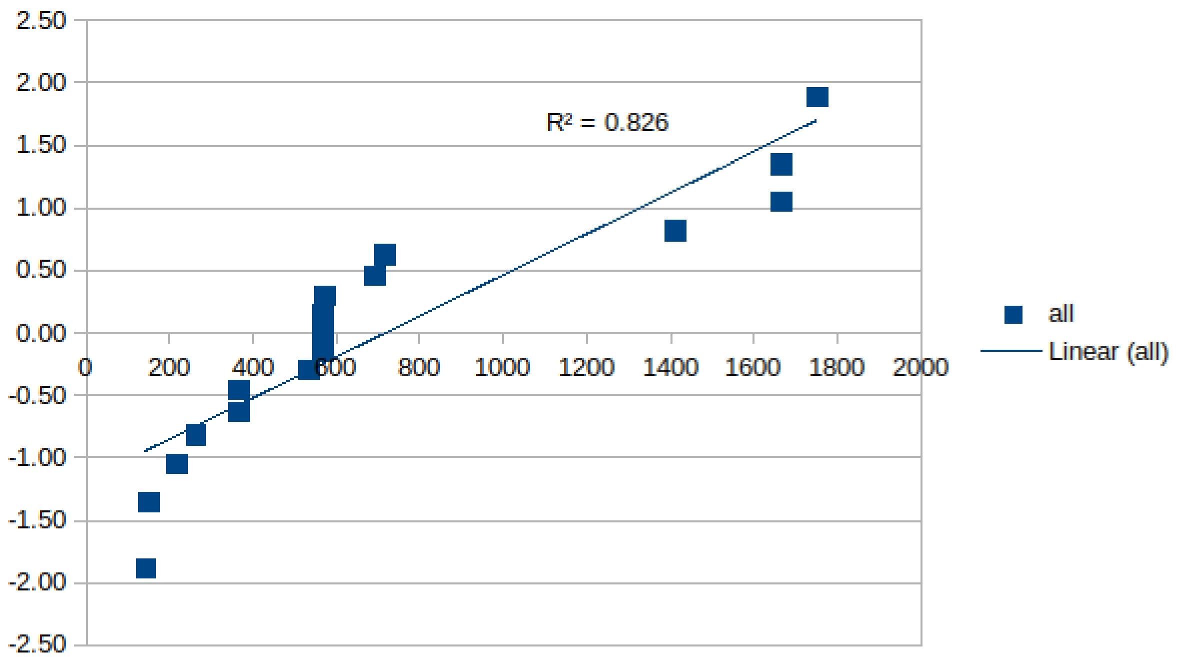
Table 4.12: Duration of planning application in England & Wales

Round	90% min	Average	90% max
1	189 (6 months)	629 (1.75 years)	1510 (4 years)
2	228 (7 months)	742 (2 years)	1256 (3.5 years)
3	441 (1.2 years)	536 (1.5 years)	630 (1.75 years)

As identified above, the number of Scottish projects does not lend itself to statistical review per round (1 Round 1 site, 0 Round 2 sites, 4 STW Sites and 2 round 3 sites). However there is some scope if all the applications are bundled together.

The chart below (figure 4.3) shows the normality plot for all Scottish sites across the rounds (NB there were no Scottish sites in Round 2).

Figure 4.3: All Scottish sites (Normality Plot)



This is still far from normally distributed, however the 4 long approval times relate to projects which were held pending appeal of a judicial review – a clear special cause of variation. The shorter duration sites are all demonstration sites which are also arguably 'special cause' variation. Removing these special cause variation items gives the following range of planning duration (shown in table 4.13 below).

Table 4.13: Duration of planning applications in Scotland

Round	90% min	Average	90% max
All	275 (9 months)	500 (1.4 years)	725 (2 years)

Returning to the questions posed of the sub-system earlier it can be seen that;

- The planning system does result in consent being granted in a high proportion of cases
- The consenting process takes approximately 18 months to complete after submission
- The process is becoming more predictable with each round – although special causes of variation can greatly impact on timelines.

The planning sub-system can therefore be considered to be functioning in each of the UK territories, albeit with a great deal of complexity and variation.

4.4.2 The Finance sub-system

Offshore Wind Farm projects have a particular profile of finance requirements. The projects can be considered to have a number of phases.

- Development stage (up to planning application)
- Detailed development – post consent leading up to Final Investment Decision (FID)
- Pre-construction
- Construction

The greatest investment need is at the pre-construction and construction stage where financial requirements for a multi-hundred MW wind farm are in the £Billion scale. During the initial development stages, financing requirements are still large (£10s Million to £100s Million) but are one or more orders of magnitude less than during construction. Post-construction the capital requirements are limited to operations and maintenance support and are assumed as operational expense items up to decommissioning. At this time there is limited experience to test this assumption.

Project risks relating to finance (time and expenditure) are therefore very much concentrated in the construction phase.

The developers of offshore wind come in 2 different types:

- Independent developers whose business focus is on bringing capacity to market
- Utilities who own and manage existing capacity (potentially in many different generating technologies) as well as developing new capacity

There are a variety of types of finance available to developers, and the type used varies for the different types of developer.

- **Non-recourse finance.** In this type of finance the debt is secured against an asset as collateral. In the event of default the lender can seize the collateral but cannot pursue the borrower for any shortfall between the collateral value and the loan value. This is an important form of finance for independent developers.
- **Balance sheet finance.** In this type of finance the borrower adds the capital used to balance sheet statement e.g. by transferring from reserves or other capital raised against the whole business. This form of finance is usually only available to utilities due to the relative scale of the project value to the whole business value.
- **'Green' Bond Finance.** Green Bonds are a particular form of debt finance recognised by markets as being specifically linked to financing of projects that offset climate change threats. Electricity generation from renewable sources is a clear example. Green Bonds can be issued by any corporate body but multi-national investment bodies such as the World Bank and the European Investment Bank (EIB) have specific offerings.

Much on the development of Offshore wind Power has been undertaken during the worldwide financial crisis and subsequent recession. Only 6 Round 1 wind farms (out of 13) had commenced construction before 2008 when the crisis emerged. The aftermath of the financial crisis was typified by significant restrictions on the levels of funding allowed by banks and a greatly reduced acceptance of risk in any loan. In the early Offshore Wind Conferences (2011 – 2014), the scale of finance required was a frequent conversation topic.

The changing nature of government support for renewables in the UK also has an impact on the financing landscape. Under the ROC regime, sites were not accredited for ROCs until they had been commissioned. Any financing of construction was therefore at the risk that the sight would not be accredited. This was considered to be a low risk and indeed no offshore wind farms were refused ROCs.

A bigger impact of the ROC regime is that the actual value of generated electricity is not known. The value of the ROC is a ‘top-up’ to the wholesale price received by the generator. Project financial appraisal is therefore less certain and must make a risk judgement.

The CfD regime changed the financial environment quite considerably. Projects had the (real and demonstrated) risk that, while being compliant, the project may not win a CfD at auction and so have no way to demonstrate a financial return to investors (hence no route to market). Final Investment Decisions must therefore come after the winning of a CfD i.e. the project will not enter the pre-construction phase until a CfD is awarded. The earliest CfD round was described as a financial investment decision enabling round.

Another feature of the CfD regime is that the mechanism provides certainty over the value of generated electricity for a period of 10 years – the ‘Strike Price’ bid for in the auction. Project financial appraisal can therefore work from a more concrete income figure.

A number of types of lending organisation have been involved:

- Commercial Banks
- Policy driven lending by EIB, EDB
- Investment Funds (e.g Macquarie Capital, Copenhagen Infrastructure Partners)
- Pension trusts (e.g. Pension Insurance Corporation)

Despite early concerns about access to funding, all the projects that have reached the final investment decision point (i.e. planning consent has been granted for a deployable project and a route to market is available, ROC or CfD) have gained the necessary finance. The one project which observers expected to struggle (Neart Na Goithe) was sold on to a utility for the construction phase. The 2013 report on offshore wind financing “*Where's the money coming from?*” (EWEA, 2013), the authors note that;

> “[finance is] *not widely considered the main constraint to the deployment of offshore wind compared to factors such as regulatory and political risk, and grid connections.”*

A number of features of the financing activity can be interpreted as demonstrating a maturing investment environment in the offshore wind power sector;

- **Growth in non-recourse funding:** This suggests that financing institutions are increasingly comfortable that there is inherent value in offshore wind power assets.

- **Commonality of bank lenders' requirements:** As banks have become more knowledgable about the industry, there is greater commonality in lending terms reducing the transaction overhead in seeking such finance.
- **Recycling of debt:** The stages up to construction completion are the riskiest of offshore wind projects. The ability to refinance once a project is operational improves the long term economics of the project and releases more risk tolerant financing for future projects.
- **Increasing Pension Fund ownership:** The increasing involvement of pension funds in the refinancing of debt on operational wind farms is taken as recognition of well understood (low) risk in the industry.

As well as supporting the general emergence of the offshore wind power industry, the maturing financial picture has an impact on the longer term future of the industry. As has been identified elsewhere, achieving a Levelised Cost of Energy (LCoE) of less than £100/MWhr by 2020 is a key goal for the industry. Table 4.14 below contains a very simple financial model that shows the impact that a reduced risk premium has on LCoE. All the figures in the table are the author's own and are for illustrative purposes.

Table 4.14: Effect of Reducing Risk Premium on LCoE

Factor	**12% Cost of Capital**	**6% Cost of Capital**
Capital Cost per MW	£3,000,000	£3,000,000
Finance rate	12.00%	6.00%
Annual Operating Cost per MW (A)	£100,000	£100,000
Load factor	40.00%	40.00%
Project life	20	20
Electricity Generated per year (MWh) (B)	3504	3504
Period Payment (C)	£401,636	£261,554

LCOE ((A+C)/B) (£/MWh)	£143.16	£103.18

As can be seen reducing the cost of capital for a given project (while maintaining all other factors) has a significant impact on reducing the Levelised Cost of Energy.

It is clear from the WindEurope annual review that the financing of offshore wind is a global business with over 50 active lenders from within the EU, Japan and North America. The UK is the largest single market, with 48% of cumulative investment by 2018 with Germany following at 34%. (WindEurope, 2019). The following charts (figures 4.4 and 4.5 below) show the growth in funding in Europe, with the UK data shown where available. The data has been gathered from WindEurope's (was EWEA) annual offshore wind statistics publications 2011 – 2018.

Figure 4.4: Financing of new capacity in European Offshore Wind

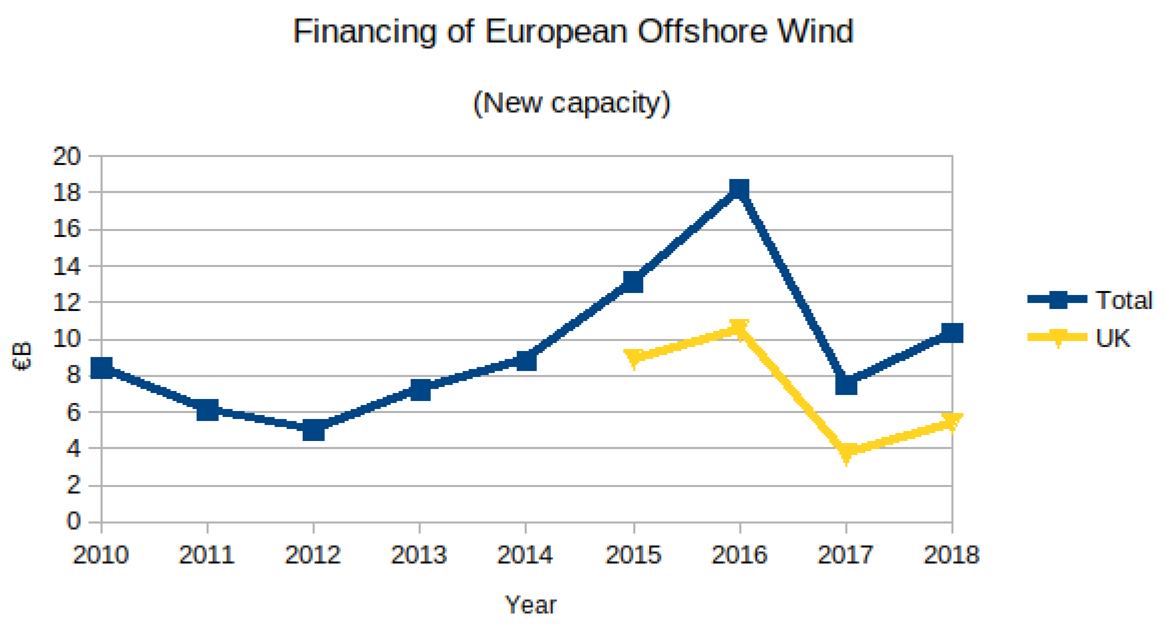
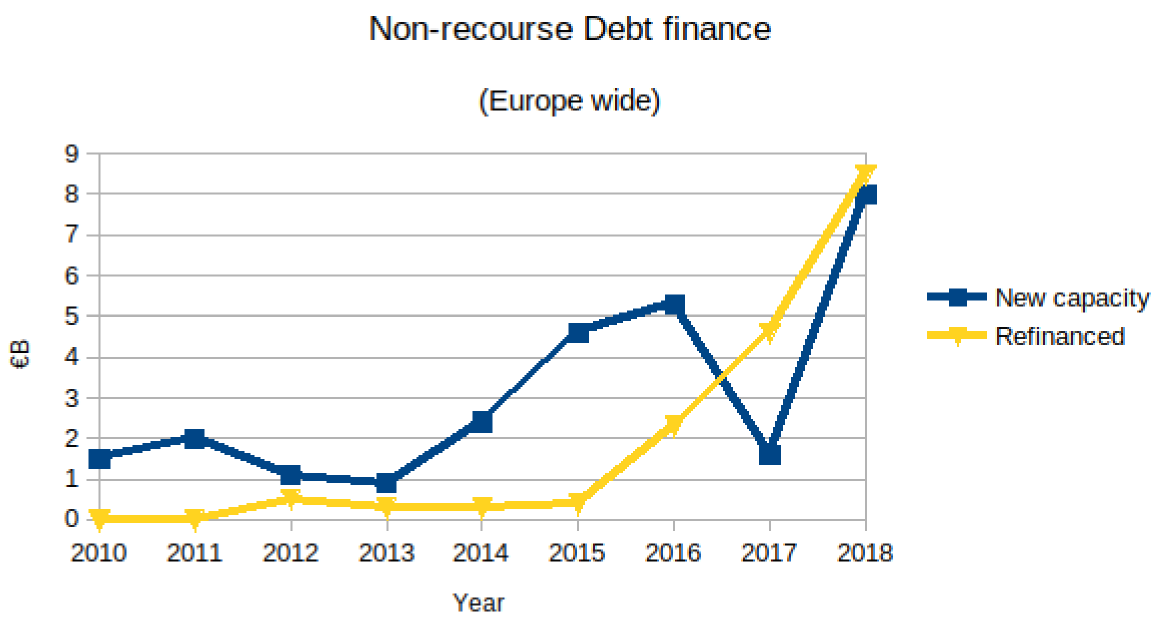


Figure 4.5: Rise of Non-Recourse Debt in Offshore wind Financing.



In summary, offshore wind power is supported by a complex but mature and functioning finance ecosystem with a diverse range of active lenders and a number of alternate financing options available. The early concerns about the availability of finance for the large installed capacity have not come to pass. This may be in part because the rate of installation is at the low end of expectations. The well-functioning finance system has played a significant part in the industry goal of achieving a LCoE less than £100/MWhr.

4.4.3 The Market Sub-system

The market for offshore wind has its roots in the de-regulation of the UK power market in 1989. Prior to this all energy utilities were nationalised. The Electricity Act 1989, which enacted the privatisation, included specific obligations of the resultant 'Public Electricity Suppliers' (PES) to purchase electricity from non-fossil fuel generators (e.g. hydo-electric, nuclear, onshore wind). The main recipient at this time was nuclear power. The varied schemes used by the different UK regions are known as the NFFO (non-fossil fuel obligation).

The NFFO scheme changed in 2002. The NFFO was identified to have delivered only 25% of the non-fossil fuel electricity contracted for (postnote, October 2001) and a different scheme was therefore required. The replacement introduced Renewable Obligation Certificates (ROC) whereby each MWh of fossil fuel generation was required to be balanced by a portion of a ROC in line with the aimed for proportion of energy to come from renewable resources (This portion was set at 3% at the start of the scheme in 2002, rising to 10.4% in 2010-11. [Figures from UK government Renewables Obligations Orders 2005, 2016]). Generation of 1 MWh of electricity from an accredited facility provided 1 ROC. ROCs were not available to nuclear generators.

To meet its obligations an electricity supplier had to either purchase the requisite number of ROCs from a renewable generator or 'buy out' ROCs from the scheme administrators (OFGEM). Failure to produce enough certificates resulted in 'buy-out' penalty at a rate set by government. At the end of a given period (year) the fund from 'buy-out' penalties is distributed to generators presenting ROCs in proportion to the number of ROCs presented.

The scheme was enacted to meet agreed European targets for the reduction of CO2 and placed a requirement on electricity suppliers to source an increasing proportion of electricity from accredited renewable generation sources. This summarised in table 4.15 below.

Table 4.15: Increasing ROCs

Obligation period	ROCs/MWh supplied (Great Britain)	ROCs/MWh supplied (N. Ireland)
2002/03	0.030	n/a
2003/04	0.043	n/a
2004/05	0.049	n/a
2005/06	0.055	0.025
2006/07	0.067	0.026
2007/08	0.079	0.028
2008/09	0.091	0.030
2009/10	0.097	0.035
2010/11	0.104	0.040
2011/12	0.114	0.050
2012/13	0.124	0.063
2013/14	0.134	0.063
2014/15	0.144	0.063
2015/16	0.154	0.063
Every year until 2036/37	0.154	0.063

Accredited generation suppliers get ROCs for 20 years from the point of accreditation. The process requires that the generation site is commissioned at the point of application. The mechanism allows for pre-submission of applications and so the period of ROC accreditation can be considered to start from the commissioning of generating capacity.

ROCs provided a market mechanism to support new generation technologies. Initially there was no differentiated level of support between different technologies. This changed in 2009 and Offshore Wind benefited from 2 ROCs for each MWh of generation. In 2013 a sliding scale of ROCs was announced with support for Offshore Wind dropping to 1.8 in 2016/17.

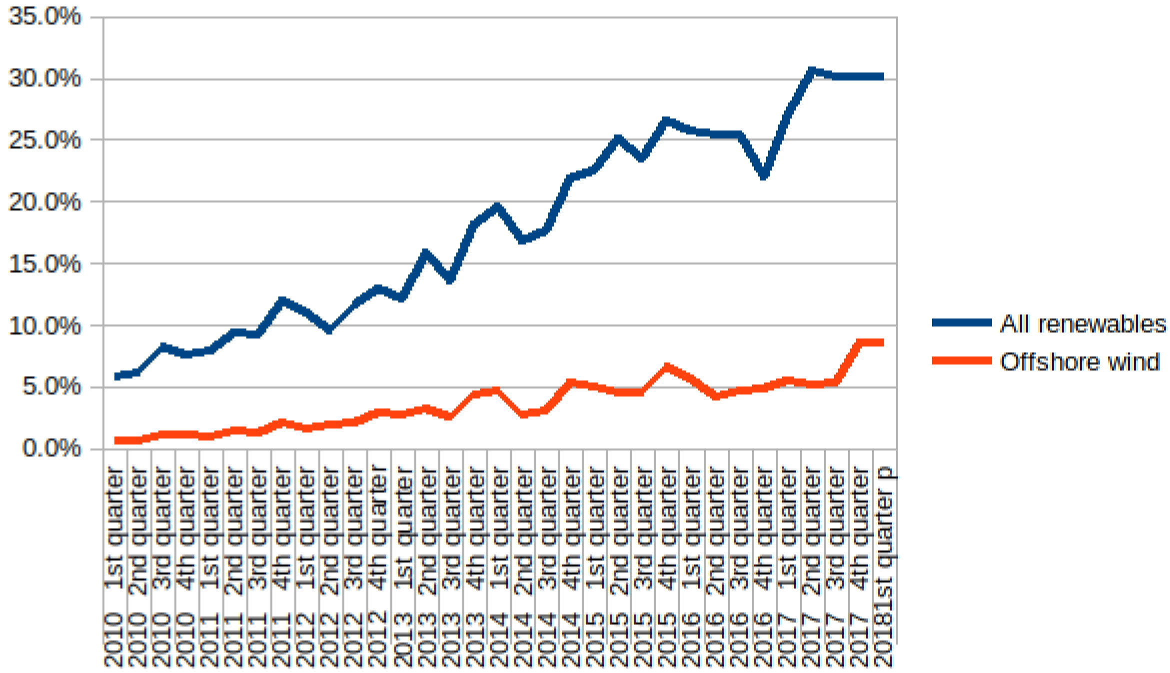
When the governing party changed in 2010 (to a Conservative / LibDem coalition) an energy market review was announced. This led to a number of significant changes affecting Offshore Wind developments:

- The ROC scheme was given an end date for new capacity of 31st March 2017 (with some transitional arrangements for capacity coming on stream in that time window)
- A new support mechanism, based on Contracts for Difference was announced to cover capacity commissioned form April 2017 onwards.
- A capacity market was introduced (in 2014) to be administered by Ofgem. In this role Ofgem would seek suppliers who would **guarantee** to supply electricity at set prices when the overall grid system required. These suppliers would be paid to make this capacity available regardless of use. The value of this capacity is set at auction for the period 4 years ahead and 1 year ahead.
- A carbon price floor (CPF) was set to address the failure of the European Union Emissions Trading Scheme (EU ETS) to set a minimum price for carbon emissions that would drive low carbon investment. A Carbon Price Support was added to the ETS to achieve a target carbon price of £30/tCO2.

As with the planning regime, the market structure for offshore wind is complicated. There are subsidies for generation, the form and level of which have changed dramatically over the period, and disincentives to use alternatives which impact on the market suppliers.

The initial goal of the NFFO and ROC schemes was to grow the level of renewables within the electricity generation mix. The following chart shows this growth between 2010 and 2017.

Figure 4.6: Growth in renewables.



In the period, renewables generation has grown from 5% to 30% of electrical demand (6-fold growth). Offshore wind has grown from 0.6% to 8.5% (14-fold growth).

Initial ROC support was £35/MWh (as a single ROC in 2002), this climbed to £100/MWh when ROC banding was introduced in 2009 (and 2 ROCs were available per MWh of offshore wind generation). By 2017 the support had declined to £44/MWh.

The support provided under the CfD mechanism is substantially different. Within the ROC regime the actual income from generation fluctuates with market prices – albeit with a top-up premium. This premium also fluctuates dependant on levels of buy-out and the ability to sell ROCs. The CfD regime by contrast pays out with reference to a contracted ‘strike’ price. This provides the generator with a more consistent income although the mechanism excludes support when prices go negative.

Projects that are applying for ROCs do not know if they are successful until commissioning. The developer (and financiers) therefore take on substantial project risk up to completion. CfDs, by contrast, are awarded before a final financial investment decision, removing an element of risk from the main capital investment stage (construction).

This more favourable position under CfDs is tempered by the process for awarding the contracts. With the ROC regime, the supplier had a number of fixed criteria to meet to be eligible. While the site might not be eligible it can be considered a low risk. The annual report on the RO scheme (Ofgem, 2019) does not identify any sites being refused accreditation. In 2011, a court case (Clarks legal , 2011)successfully challenged the decision not to award ROCs.

With the CfD regime, the contracts are let out via auction. There is therefore no guarantee that a qualifying site will gain a contract. At this stage there is no route to FID for the project and most (if not all) the development work will have been undertaken (and invested in) without a route to financial returns. CfD allocation rounds become a critical focus for the developer.

A final significant difference is the duration of a Contract for Difference. This has been set at 15 years, compared with 20 for ROC support. Expected asset life for offshore wind power is expected to be longer than this term.

There have been 3 allocation rounds for CfDs as follows:

- FID support round – this was a one off process to provide support to renewable technology projects coming to Financial Investment Decision stage at the point when the cross over from ROCs to CfDs was occurring. [DECC] . 5 offshore wind projects were supported with a total capacity of 3.2GW (3 other projects were supported in biomass and biomass with CHP technologies with a combined capacity of 1.4GW). Strike prices for offshore wind power were £140/MWh to £150/MWh
- Allocation Round 1. The first auction of CfDs occurred in 2015. The budget for this round was £315M annually. 2.1GW of generating capacity won contracts. 2 offshore wind projects were supported totalling 1.16 GW. The Offshore wind strike prices were £119.89/MWh and £113.39/MWh
- Allocation Round 2. This occurred in 2017. The round was closed to onshore wind and solar PV. The budget was £176M annually. 3.3GW of generating capacity won contracts. 3 offshore wind projects were supported, totalling 3.2GW of capcity. Strike prices were £57.50/MWh to £74.75/MWh

A fourth round is proposed for 2019. The draft budget indicated at the end of 2018 is £60M annual spend with a strike price of £56. The current base load price of electricity is £45.61. The round is intended to award contracts to 6GW of capacity coming on stream in each of 2 years 2023/24 and 2024/25. The following technologies are eligible:

Table 4.16: Technology and Administrative Strike Price (UKGov, 2018).

Technology Type	**2023/24 Strike prices (£/WMh)**	**2024/25 Strike prices (£/WMh)**
ACT	113	111
AD (> 5MW)	122	121
Dedicated Biomass with CHP	121	121
Geothermal	129	127
Offshore Wind	56	53
Remote Island Wind (> 5MW)	82	82
Tidal stream	225	217
Wave	281	268

The government has also signposted an intention to have auctions every 2 years throughout the 2020s.

At the time of writing 14GW of offshore wind projects has planning consents but did not have a CfD allocation.

The UK is not the only market available to offshore wind developers. Significant capacity has also been developed in Germany (5GW) (WindEurope, 2019) with Denmark, Netherlands and Belgium also having around 1 GW each.

The German market did not start until 2009 (with the Alpha Ventus windfarm) (WindEurope, 2019) and was held back for a number of years (up to 2015) due to the lack of grid connections for offshore farms.

Since 2017 support for offshore wind projects has been subject to auction by the German government (in line with European guidelines on State aid). In the recent auction (April 2018), the average support price for German offshore wind was 4.66ct/kWh (€46.60 /MWhr, £41.50 / MWh). A number of projects were accepted with a zero support level attached. It should be noted that the support price is not directly comparable to UK strike prices as the support mechanism is different and projects do not include the costs of grid connection.

Each of the European markets has its own characteristics e.g. grid connection costs not part of the project in Germany, site surveying carried out by the government in Denmark which makes direct comparison of energy prices inaccurate.

The UK is projected to remain the largest market through to 2030 (WindEurope, 2019) and the major markets (UK, Germany, Denmark) are projecting subsidy free developments by 2030.

Table 4.17: Projected Market Sizes 2030

Country	**Capacity at end 2017 (MW)**	**Projected capacity in 2030 (MW)**
United Kingdom	6,835	22,500
Germany	5,355	15,000
Netherlands	1,118	11,500
France	2	7,000
Denmark	1,266	4,300
Belgium	877	4,000
Poland	-	3,200
Ireland	25	1,800
Estonia	-	600
Sweden	202	300
Total		**70,050**

The market system that offshore wind businesses supply is a complex environment. There are a number of different regulatory regimes, albeit with the same goal of de-carbonising electricity generation, with changing support mechanisms over time. At the time of writing, the market for offshore wind is predominately Europe-based. The success of cost-reduction and scaling of projects has led to interest and activity in of the parts of the world, most notably China.

The added difficulties of a complex market are balanced, to an extent, by the opportunity for participants to switch focus to other (nearby) markets when progress in one stalls e.g. the UK was very active while Germany was constrained by grid connection issues pre-2015, The German market opened up (2015) at a time when the UK market was uncertain due to changes in government.

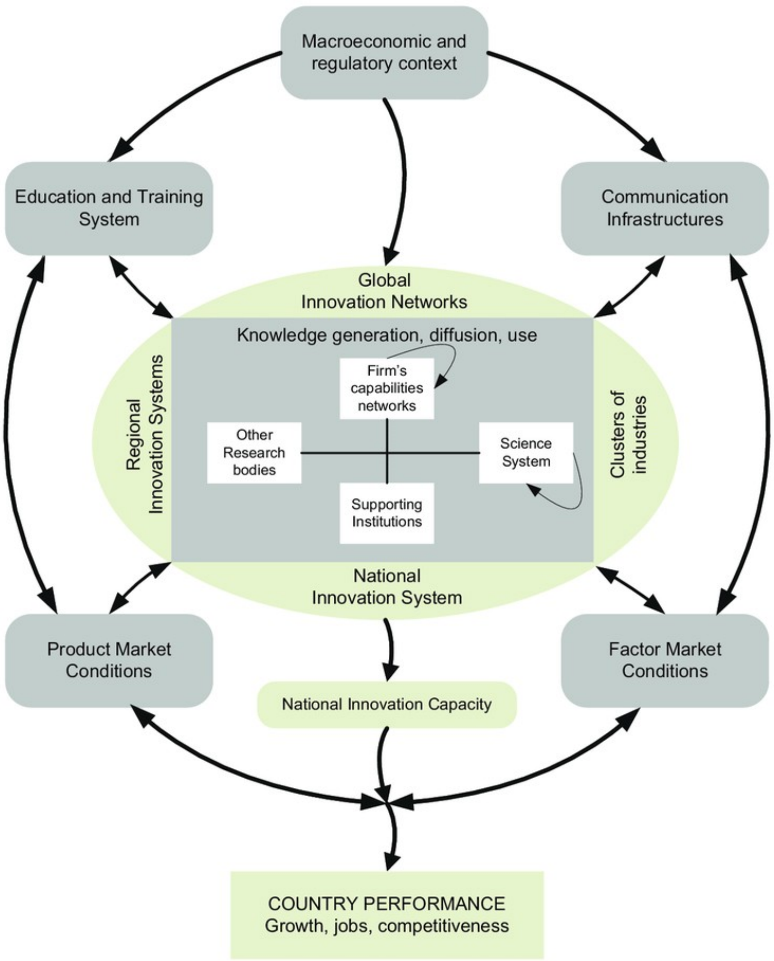
The UK is expected to remain the largest part of the largest geographic area for offshore wind. The most likely challenger for market size is China (WindEurope, 2019).

4.4.4 The Innovation Sub-system

The innovation sub-system is the collected activity by original equipment manufacturers, supply chain companies, government funded organisations, higher education establishments and others to bring new or enhanced capability to the market to meet some need.

In the UK the innovation system has reflected the broader National Innovation System pattern (shown in figure 4.7 below).

Figure 4.7: National Systems of Innovation (OECD)



For offshore wind power the firms are the OEMs such as Seimens-Gamesa, MHI Vestas, Sanvion; structures producers such as BiFab, WindTowers; electrical systems producers (Siemens) and the offshore project engineers (ABB, Atkins).

The supporting institutions are both governmental e.g. ORE Catapult, Crown Estate (via OWPB), Knowledge Transfer Network, Scottish Enterprise and non-governmental e.g. Carbon Trust, AREG, RenewableUK, Scottish Renewables.

The science system is represented by the Higher Education establishments and ‘other research bodies’ include UK Energy Research Centre, Siemens Research Centre at Sheffield etc.

The innovation system was focussed on cost reduction from an early stage. The UKERC report in 2010 (*‘Great expectations’* - Greenacre et al, 2010) highlights the issue of cost growth in early offshore developments in UK waters.

At this time the cost metric identified was frequently the capital cost per MW installed. The following table of costs per MW installed shows how early reductions in the technology were reversed by the time of the *‘Great Expectations’* report:

Table 4.18: Costs of early Offshore Wind Farms

Date	Territory	Windfarm	Cost
1991	Denmark	Vindeby	£1.82m /MW
2002	Denmark	Horns Rev	£1.05m /MW
2003	UK	North Hoyle	£1.35m /MW
2004	UK	Scroby Sands	£1.26m /MW
2007	UK	Burbo Bank	£1.83m /MW
2008	UK	Robin Rigg	£2.48m /MW

By the time of the *‘Great Expectations’* report in 2010, a figure of £3.2m /MW had been identified by E&Y in a 2009 report to the Department for Energy and Climate Change. Drivers for this cost growth were publicised to be:

- Increasing project complexity
- Deeper water installations
- Further offshore installations
- Supply chain constraints

The increasing capital cost of offshore wind was an early challenge to the stated goal of achieving a reduction in costs to make the technology affordable in comparison to other low-carbon technologies.

An alternative metric for the energy cost is the Levelised (sometimes 'Lifetime') Cost of Energy (LCoE) in which the capital cost plus annual operations and maintenance costs are divided by the annual output of energy over the life of the project. This LCoE measure in £/MWh can be very different for developments with the same capital costs – various factors impact this including meteorological conditions, unit reliability, cost of capital, access and maintainability of turbines etc. As a measure it allows closer comparison to other generation technologies.

The Offshore Wind Cost Reduction - Pathways Study (Jamieson et al, 2012) was compiled with government and industry involvement and set out a vision for reducing LCoE of Offshore Wind Power to £100/MWh by 2020. At the time of the report's commissioning the LCoE was £140/MWh.

The report concluded:

> *'Based on the evidence gathered and assuming our recommendations are followed, the CRTF* [Cost Reduction task Force] *concludes offshore wind can reach £100/MWh by 2020.'*

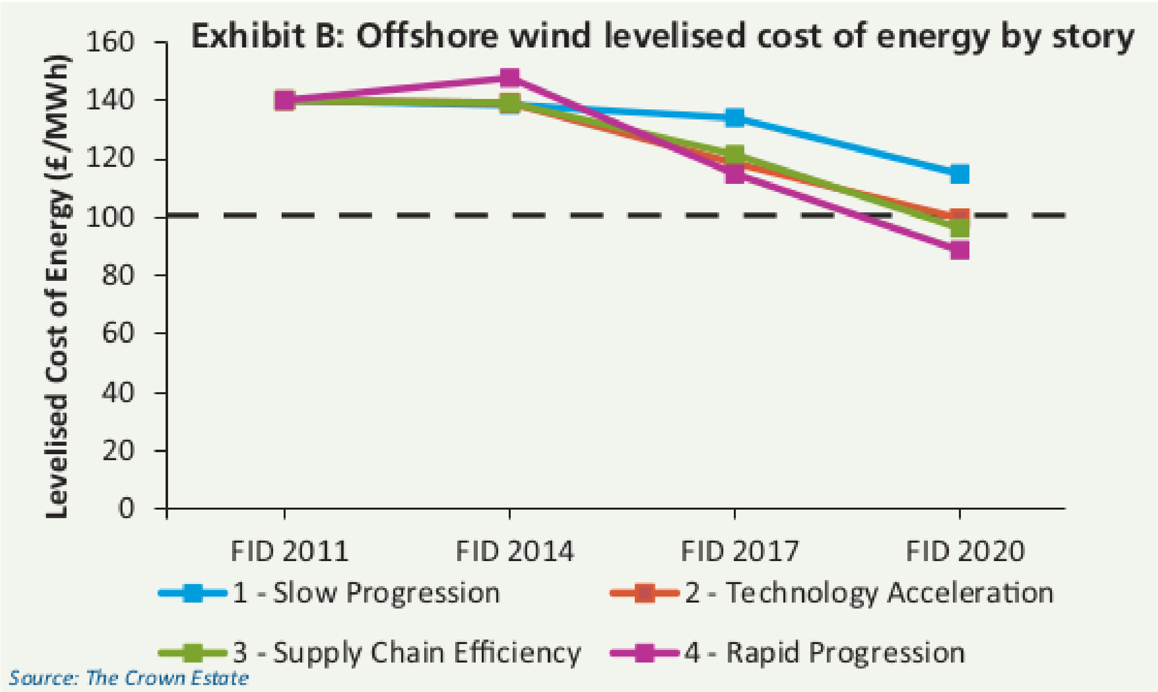
A series of 4 scenarios was set out.

Figure 4.8: Offshore Wind Power generation scenarios

Source Crown estate

The report identified projected LCoE costs by 2020 for each scenario (see figure 4.9 below)

Figure 4.9: LCOE by Scenario 2011 - 2020



The following opportunities for cost reduction were identified:

- The introduction of turbines which are larger, have higher reliability and energy capture, and lower operating costs.
- Greater competition in key supply markets (turbines, support structures and installation) from within the UK, the rest of the EU, and from low cost countries.
- Greater activity at the front end of the project including early involvement of suppliers, multi-variable optimisation of wind farm layout, more Front End Engineering and Design (FEED) and more extensive site surveys.
- Exploitation of economies of scale and productivity improvements including greater standardisation, capturing and building on learning by doing and better procurement.
- Optimisation of current installation methods.
- Mass produced support structures for use in water depths greater than 35 metres.

The Offshore Wind Industry Council (OWIC) is a senior Government and industry forum which was established in May 2013 to drive the development of the offshore wind sector in the UK. It carries this activity out via the Offshore Wind Programme Board (an industry / government collaboration) which reports back via the cost reduction monitoring framework.

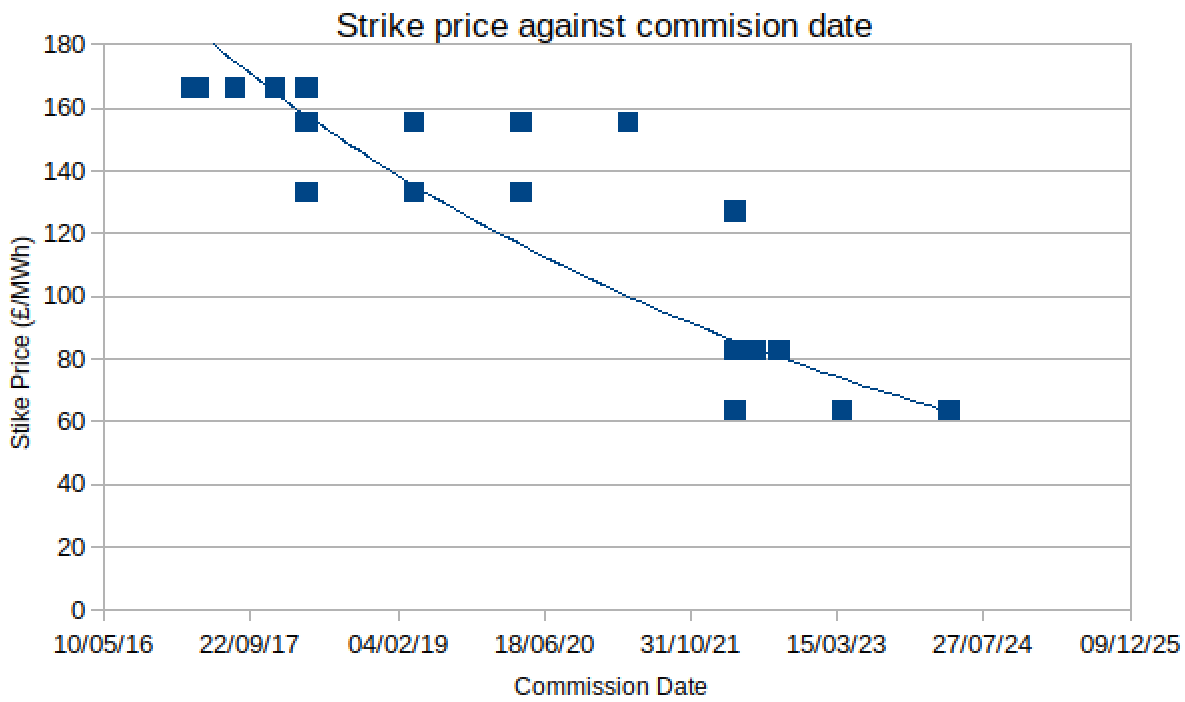
By the 2016 report, programme board was able to conclude that the goal of £100/MWh LCoE had been achieved with projects at the Financial Investment Decision point in that year having an LCoE of £97/MWh.

This cost reduction is ascribed to:

- turbines with higher power ratings (8MW machines becoming commonplace)
- increased competition (the first CfD allocation was heavily oversubscribed)
- lower cost of capital as the sector matures (an offshore wind farm's costs are largely up front – cost of servicing the debt are a major ongoing expense)

In the Allocation Round 2 for CfDs offshore wind power came in with strike prices of £74.75 for 2021/22 and £57.50 for 2022/23. This successful cost reduction for UK offshore wind comes despite the volume more closely following the 'Slow Progression' scenario in the Cost Reduction Pathways report (Crown Estate, 2012) than the others set out.

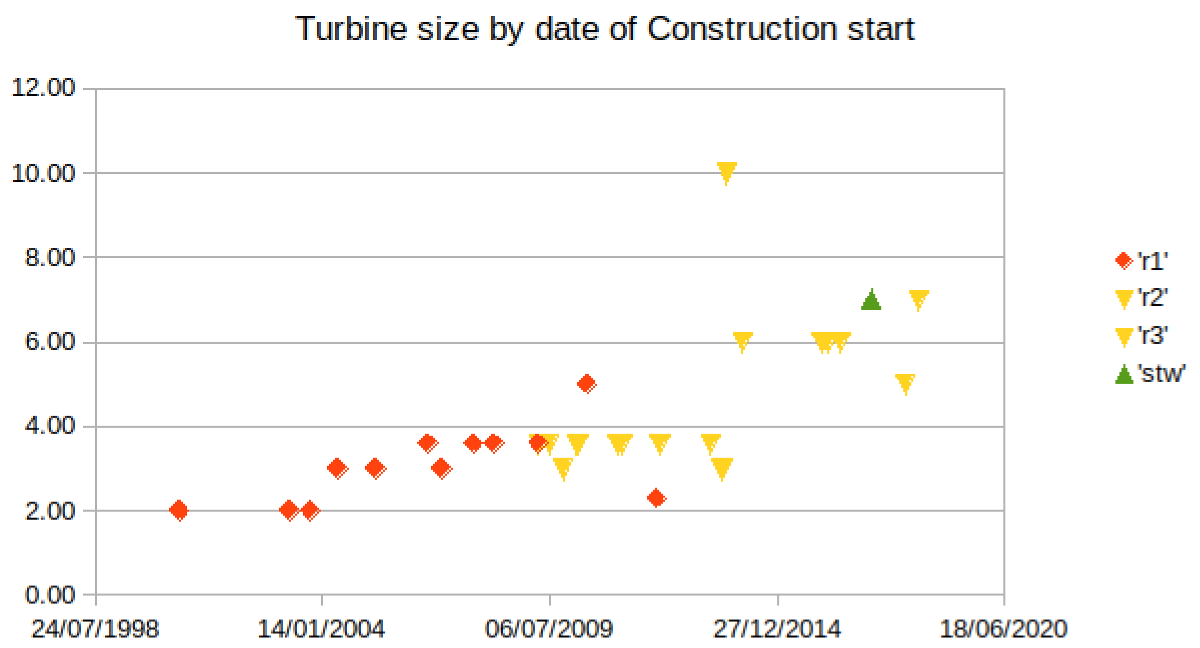
Figure 4.10: Bid Strike Prices for Offshore Wind by target commissioning date



(Source CfD company report)

A second successful output of the innovation system is the size of turbines used in developments. Figure 4.11 below shows how offshore turbine sizes have grown over the period of the study. The turbine size is only quoted for projects at the construction stage. Projects consented but still awaiting FID (following allocation of a CfD) have turbine sizes up to 12MW. Note that most onshore turbines are under 2MW capacity.

Figure 4.11: Growth in installed WTG size (by leasing round)

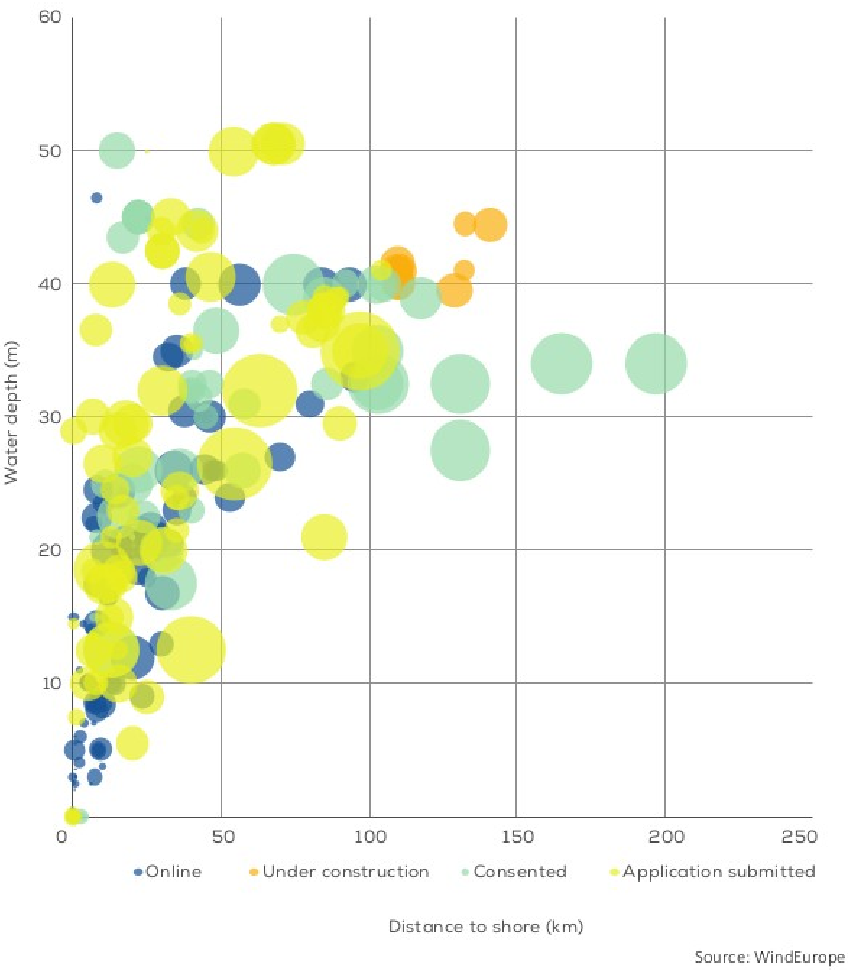


All these turbines follow the same configuration of 3-bladed, horizontal axis turbines mounted on the top of a tower structure fixed to the sea bed via a transition piece and subsea structure (foundation).

Other indicators of innovation (or at least technology change) are the types of foundations used and depth of installation / distance offshore. As projects are placed in deeper water, the type of foundations structure required changes. At the time of writing the large majority of substructures used are monopiles (>80%) and this has not changed greatly over time. Jacket substructures are the next most prevalent at 6%, with gravity base foundations closely following.

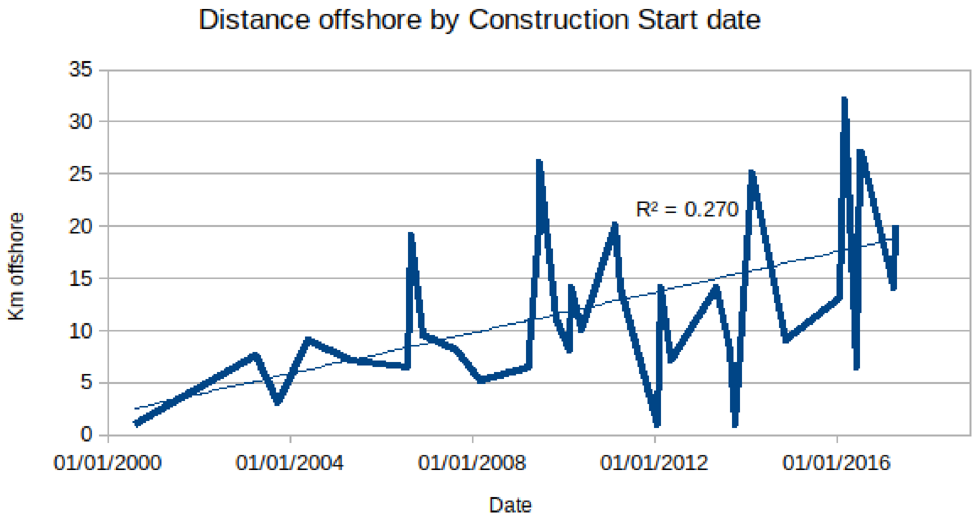
At some point there will be a change as projects are increasingly far offshore and in deeper water. Figure 4.12 below shows how European fixed structure offshore wind farms are increasingly further offshore and in greater depths of water.

Figure 4.12: WTG depth and distance from shore by project stage (WindEurope, 2017)



The distance offshore metric is mirrored in UK projects, with projects under construction increasingly far from shore.

Figure 4.13: Distance offshore for UK wind turbines



In summary, the successes of the innovation system for offshore wind have not been through radical innovation. The innovation has come from detail developments and scaling of wind turbines. All deployed wind turbines are 3-bladed upwind turbines, just as they were in 1991. Drivetrains are beginning to see a split between direct drive and geared systems (geared systems being the 'traditional' variation). Nor has this innovation been driven by competition between large numbers of OEM producers – 2 companies (Siemens-Gamesa and MHI Vestas) have over 93% of the installed base of offshore wind turbines in Europe (WindEurope, 2018).

There is evidence of more radical innovation coming through in future. New innovations in offshore wind power just developing at the time of writing include:

- Floating wind turbines with a live demonstration project and 2 others consented
- 2-Bladed wind turbines on open framework towers under-going demonstration

This suggests a different pattern of innovation for an emerging industry within a CoPS environment. In mass manufacture industries it is seen that radical innovation precedes the establishment of a dominant design, as the market mature innovation activity occurs in the process rather than the product. In Offshore Wind Power the product innovation has been incremental, and it is at the point of emergence that more radical innovation is been proposed.

4.4.5 The Installation Sub-system

The construction and installation of wind turbines is the central activity for offshore wind power at the emergence stage of its industry life cycle – without wind turbines offshore, there is no prospect of there being an industry.

This section looks at the performance of this sub-system over the duration of offshore wind power to date. The key factors looked at are;

- the number of wind turbine units being constructed
- the nominal distance offshore of turbine placement (one figure per project)
- the scale of the turbines being constructed
- the length of time projects take to construct

Table 4.19 below sets out this data in order of development rounds and construction start date (source BEIS, 2018).

Table 4.19a: Construction Timeline for UK Offshore Wind Farms (Round 1)

Site Name	Installed Cap’y (MW)	No. of Turbines	Distance Offshore (km)	Offshore Wind Round	Under Const’n	Oper’l	Days In Const’n
North Hoyle	60.0	30	7.5	1	03/04/03	01/12/03	242
Scroby Sands	60.0	30	3	1	01/10/03	01/03/04	152
Kentish Flats	90.0	30	9	1	01/06/04	10/09/05	466
Barrow	90.0	30	7	1	01/05/05	01/04/06	335
Burbo Bank	90.0	25	6.4	1	01/08/06	18/10/07	443
Robin Rigg West	84.0	28	9.5	1	01/12/06	18/07/09	960
Robin Rigg East	90.0	30	9.5	1	01/12/06	28/04/10	1244
Rhyl Flats	90.0	25	8	1	01/09/07	28/12/09	849
Lynn	97.2	27	5.2	1	01/03/08	15/03/08	14
Inner Dowsing	97.2	27	5.2	1	01/03/08	20/04/08	50
Gunfleet Sands	108.0	30	6.4	1	01/04/09	24/07/09	114
Ormonde	150.0	30	10	1	01/06/10	22/02/12	631
Teeside Offshore	62.1	27	1	1	01/02/12	31/08/13	577

Table 4.19b: Construction Timeline for UK Offshore Wind Farms (Round 2

Site Name	Installed Cap'y (MW)	No. of Turbines	Distance Offshore (km)	Offshore Wind Round	Under Const'n	Oper'l	Days In Const'n
Gunfleet Sands II	64.8	18	8	2	01/04/09	24/07/09	114
Sheringham Shoal	317.0	88	20	2	30/06/09	29/10/12	1217
Greater Gabbard	504.0	140	26	2	01/07/09	07/09/12	1164
Thanet	300.0	100	11	2	01/11/09	16/09/10	319
Centrica (Lincs)	270.0	75	8	2	01/03/10	24/07/13	1241
Walney1	183.6	51	14	2	10/03/10	30/05/11	446
London Array 1	630.0	175	20	2	01/03/11	06/04/13	767
Walney 2	183.6	51	14	2	09/04/11	06/04/12	363
Gwynt y Mor	576.0	160	14	2	01/03/12	18/06/15	1204
West of Duddon Sands	389.0	108	14	2	21/05/13	30/10/14	527
Humber Gateway A	219.0	73	8	2	30/08/13	30/05/15	638
Westermost Rough A	210.0	35	25	2	28/02/14	26/05/15	452
Dudgeon East	402.0	67	32	2	17/03/16	15/10/17	577
Race Bank (1)	286.5	46	27	2	07/07/16	08/06/17	336
Race Bank (2)	286.5	45	27	2	07/07/16	01/02/18	574

Table 4.19c: Construction Timeline for UK Offshore Wind Farms (Round 3 & Round 2 extension)

Site Name	Installed Cap'y (MW)	No. of Turbines	Distance Offshore (km)	Offshore Wind Round	Under Const'n	Oper'l	Days In Const'n
Kentish Flats 2	49.5	15	9	2.5	26/11/14	14/09/15	292
Rampion	400.0	116	13	3	25/01/16	26/11/17	671
Burbo Bank Extension	258.0	32	6.4	2.5	10/06/16	27/04/17	321
Galloper	353.0	56	27	2.5	29/07/16	30/03/18	609
Walney 3	660.0	110	14	2.5	01/04/17	01/07/18	456

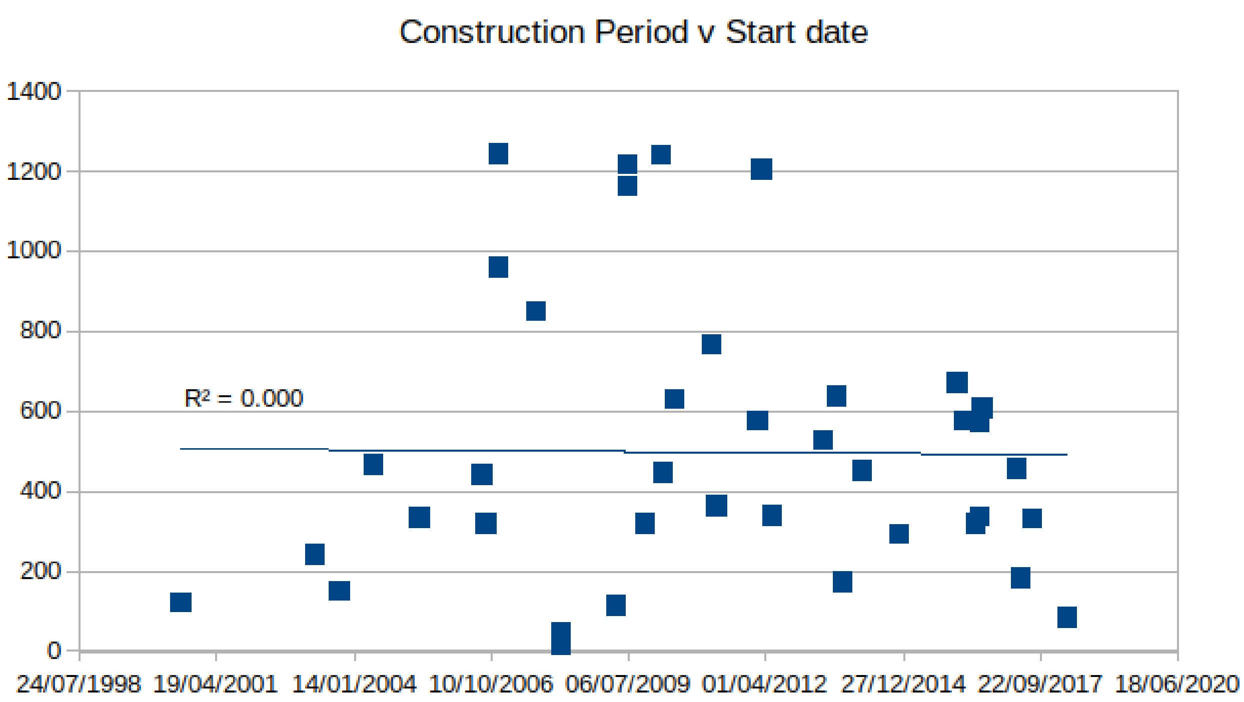
Table 4.19d: Construction Timeline for UK Offshore Wind Farms (Demo sites)

Site Name	Installed Cap'y (MW)	No. of Turbines	Distance Offshore (km)	Offshore Wind Round	Under Const'n	Oper'l	Days In Const'n
Blyth Offshore	4.0	2	1	Demo	01/08/00	01/12/00	122
Beatrice Demo	10.0	2	19	Demo	01/09/06	17/07/07	319
Gunfleet Sands - Ext'n	12.0	2	7	Demo	15/05/12	19/04/13	339
Levenmouth demo	7.0	1	1	Demo	08/10/13	31/03/14	174
Hywind Scotland Pilot Park Demonstrator	30.0	5	20	STW	27/04/17	27/10/17	183
Blyth Offshore Wind Test Site	41.5	5	2	Demo	28/07/17	25/06/18	332
European Offshore Wind Deployment Centre (EOWDC)	93.2	11	3	Demo	07/04/18	01/07/18	85

With a reasonable sized sample of projects some numerical analysis of performance is possible to gauge how the construction process has matured over time.

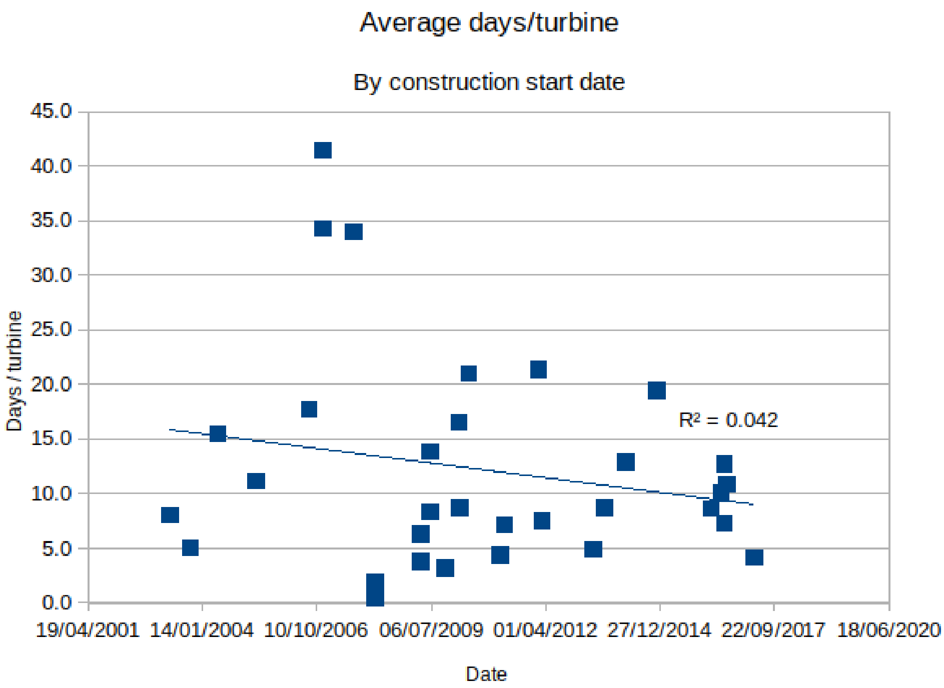
Figure 4.14 below shows construction duration against construction start date.

Figure 4.14: Construction Duration against Start Date



There is no evidence of construction experience reducing the length of time taken for projects to complete. It may be that any correlation between time for construction and start date is obscured by increasing size of wind farms in construction. Figure 4.15 shows average construction time per turbine in project.

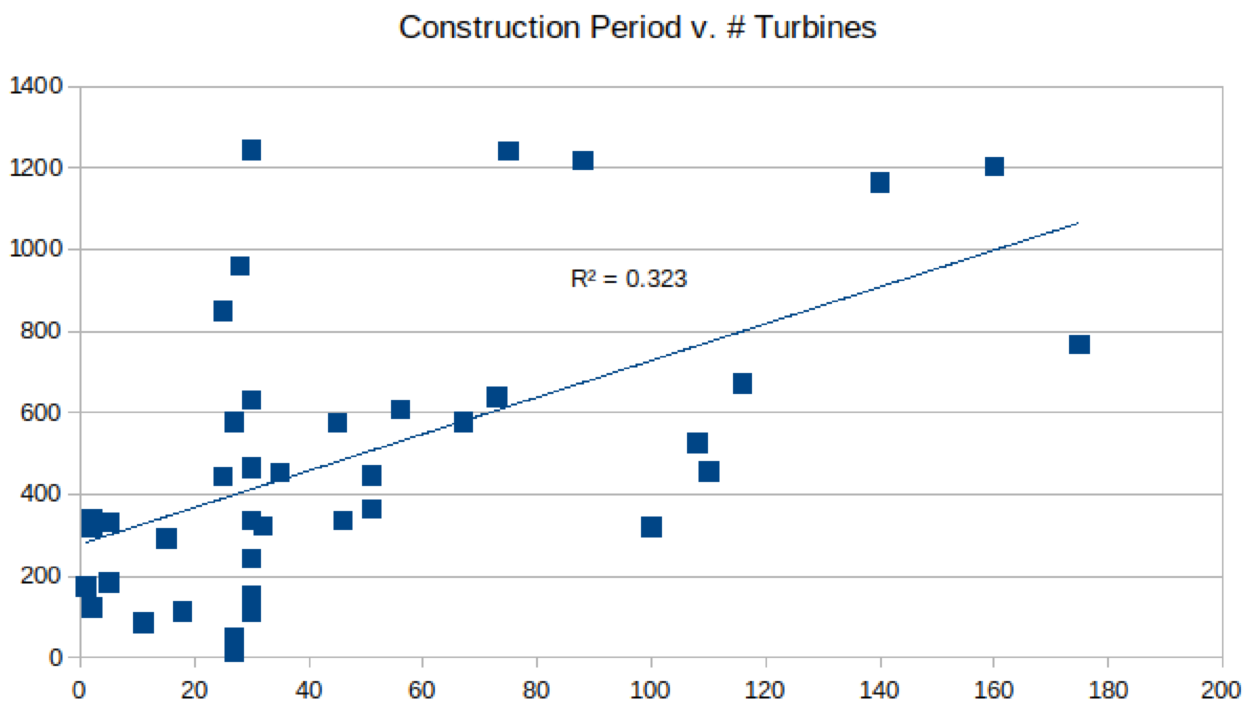
Figure 4.15: Average construction time per turbine against construction start date.



Here there is a very small level of correlation between the average construction days per turbine and the start date of construction suggesting a small learning benefit over time. A bigger effect that is apparent is the reduced spread of time per turbine in the 6 projects starting in 2017. This is investigated more when looking at the changes round by round.

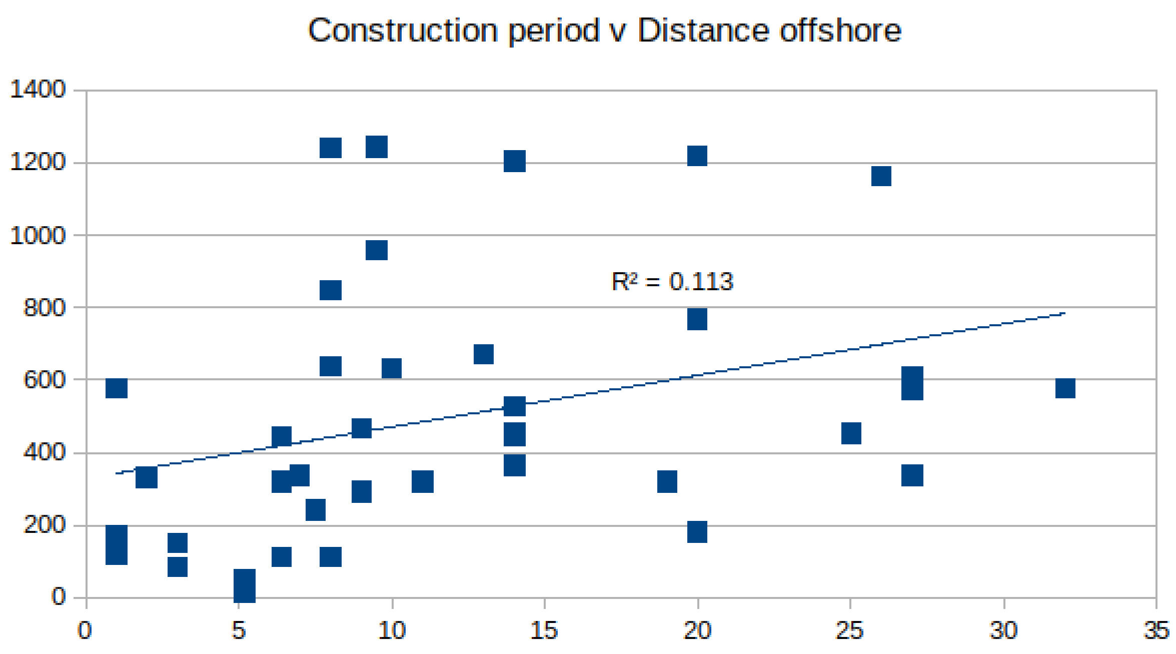
There are stronger correlations between Construction Duration and Number of Turbines installed, and Construction Duration and Distance Offshore. See figures 4.16 and 4.17 below.

Figure 4.16: Construction Duration against Number of Turbines



The correlation between construction period and number of turbines in a project is a corollary of the minimal reduction in construction time per turbine – if that measure is static then more turbines will longer construction periods.

Figure 4.17: Construction Duration against Distance Offshore

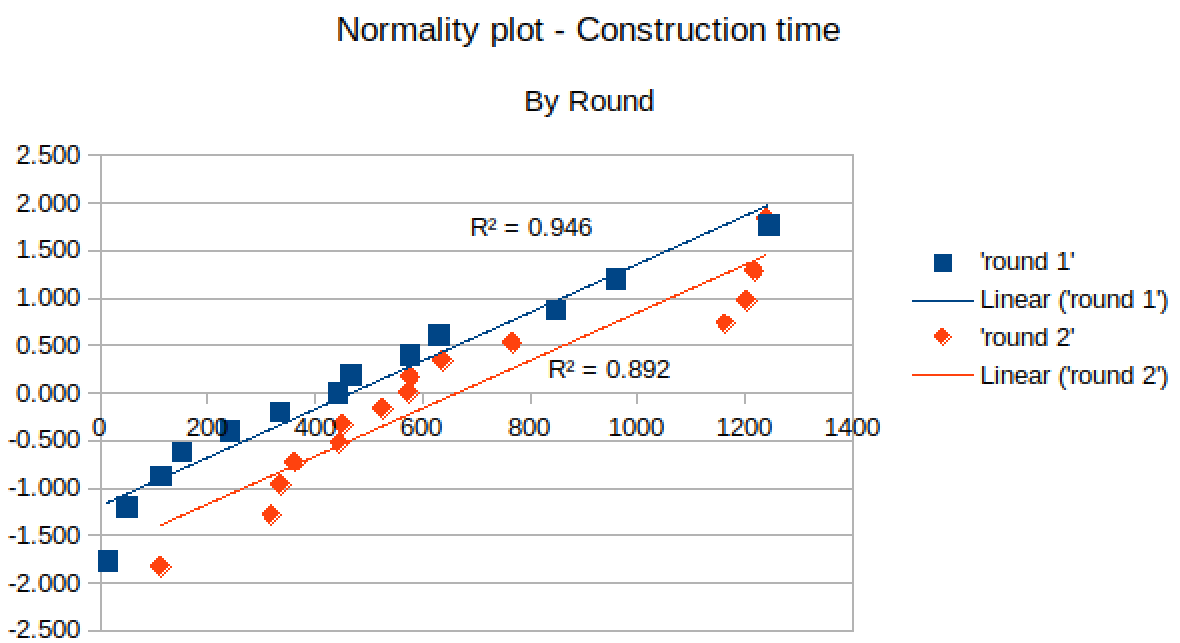


Some level of correlation between construction period and distance offshore is to be expected just from the impact of logistics. As installations distances get further offshore then travel time to sites must increase. This impact is compounded by the later, larger projects being further offshore.

With a total of 43 wind farm sites operational, and with 7 of those designated as demonstration sites which are by definition special cases, there is limited scope for a statistical analysis of construction duration by round but it can provide additional support to the investigation of what learning effects have been seen.

Figure 4.18 below shows the normality plot for Rounds 1 and 2 sites to assess whether the distribution of construction time has a normal distribution. This will confirm whether there is any basis for further statistical analysis of the data.

Figure 4.18: Normality Plot of Construction Duration by Round



The Round 1 site construction duration is shown to be normally distributed, while the Round 2 sites include 4 outliers at long durations (from 1160 days / 3 years) that reduces the confidence that the construction time is normally distributed.

The average construction time is shown in Table 4.20 below along with 90% confidence limits for duration. For this calculation the outlier data points for Round 2 are excluded as they are assumed to be special cases (no project specific data is available to determine this).

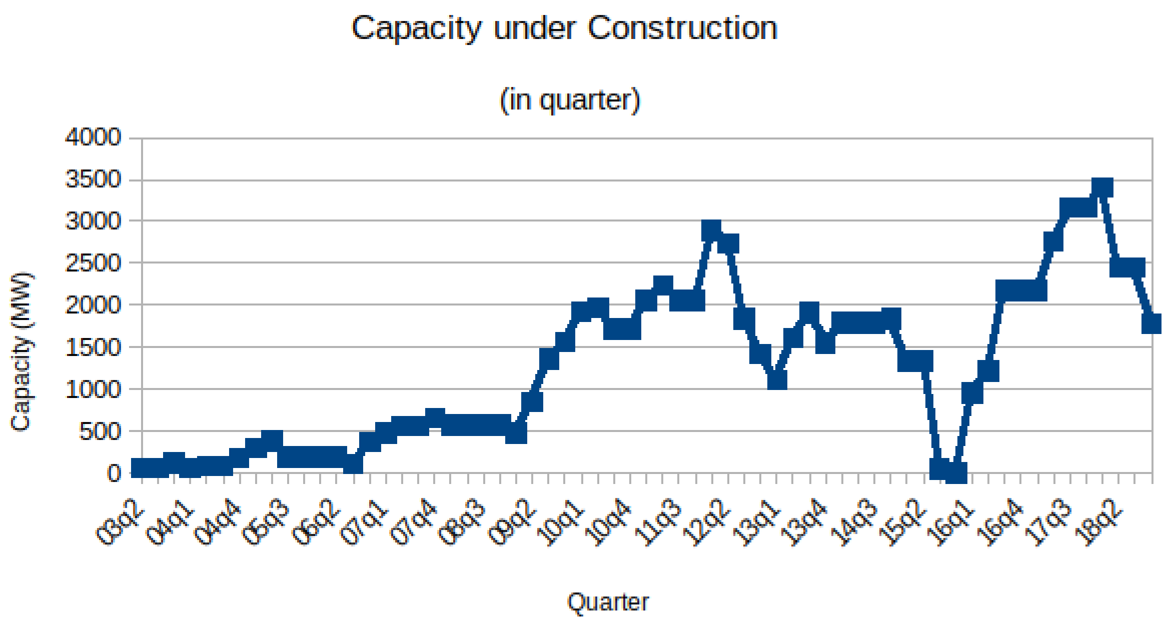
Table 4.20: Average Construction time for Round 1 and Round 2 windfarms.

Round	-90% (1.65SD)	Average	+90% (1.65SD)
1	-38	547	1131
2	169	465	761

Although there is no meaningful reduction in the average construction time from Round 1 to Round 2 (to be expected due to the low level of correlation between start date and duration), there is a greatly reduced spread of construction times. 90 % confidence limits put Round 2 construction between 6 months and 2 years.

The capacity under construction at any given period varied greatly over the study period. This is shown in figure 4.19 below.

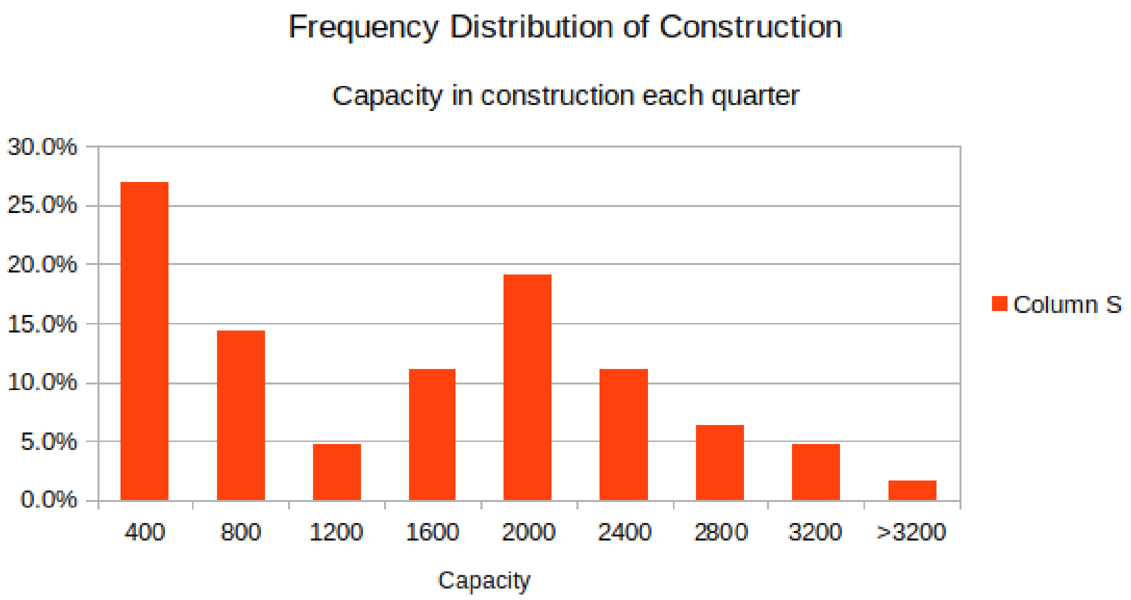
Figure 4.19: Capacity under Construction in quarter 2003 - 2018



This leads to the question whether there is some capacity restriction on the installation process and this can be partially answered by looking at the distribution of capacities under construction in each quarter. If an upper limit that has been approached some truncation of the distribution can be expected.

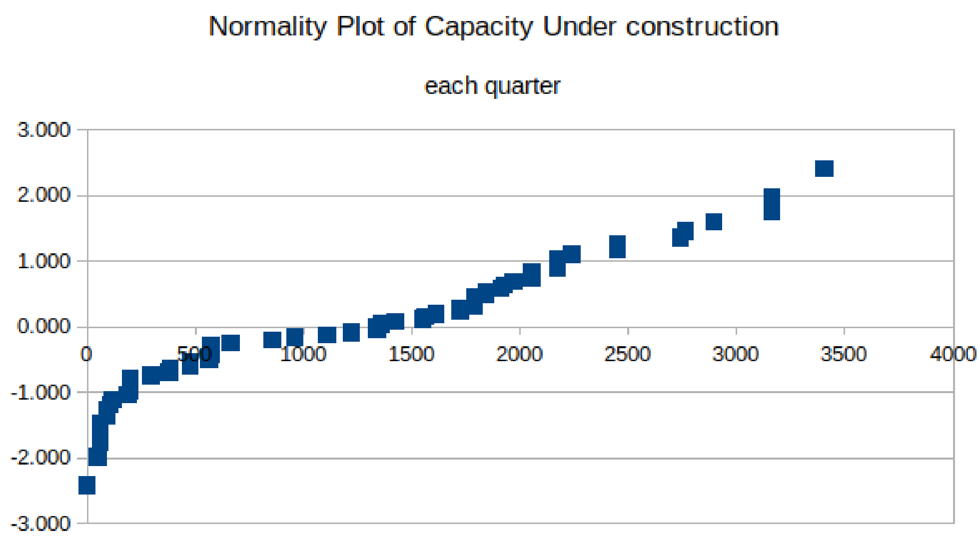
Figure 4.20 below shows the frequency distribution of capacity under construction for each quarter from the chart in figure 4.19 above.

Figure 4.20: Frequency Distribution of capacity under Construction in quarter



This can be further examined via a normality plot of the data as in Figure 4.21 below.

Figure 4.21: Normality plot of Volume under construction each quarter



There is no indication of a constrained capacity for wind farm construction (i.e. there is no skew to the distribution at the high end). The skew at low end implies that there are some special causes which result in low amounts of capacity under construction in particular quarters. This is to be expected and would be caused by a number of factors. Some examples of which are;

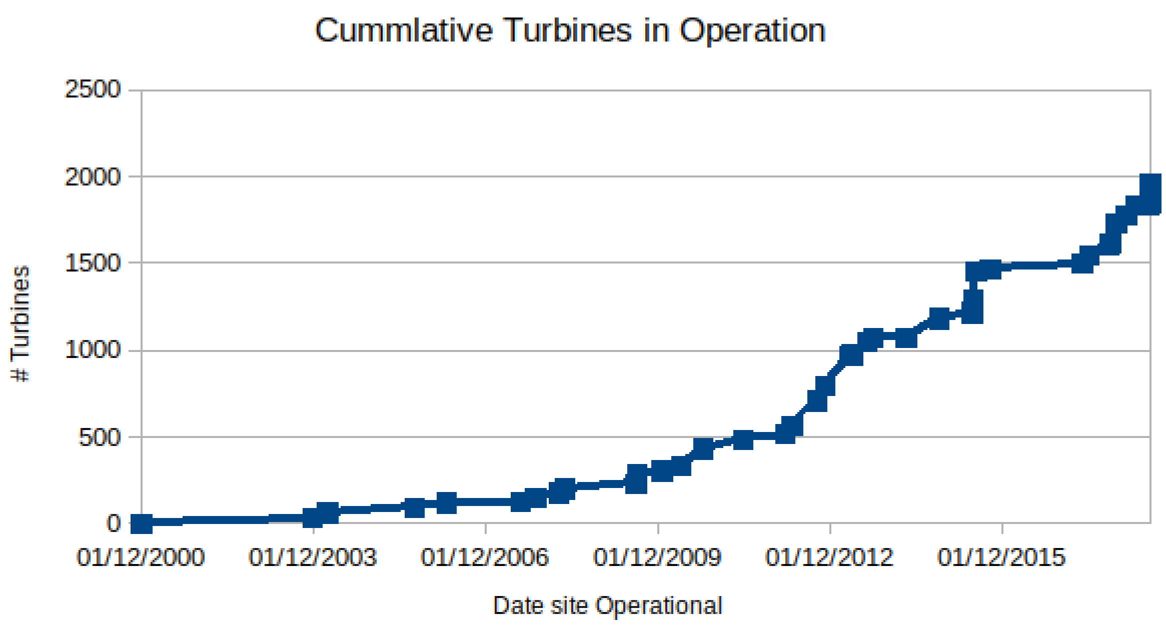
- Delay in project start due to weather
- Delay in project FID
- Lack of live projects to operate on

Overall the installation sub-system can be seen to be operating in a stable manner. There do not appear to be any capacity constraints on installation. It is notable that there is limited evidence of learning benefits over time or the installation of wind turbines. This suggests that the success in cost reduction has come from the capital equipment costs (and financing costs as discussed above) rather than a reduction in the services elements of the installation. This would not include any *price* reduction coming from greater confidence in project timelines.

4.4.6 The Operations and Maintenance Sub-system

The final sub-system identified is Operations and maintenance – the activities that support the ongoing generation of electricity through maintenance and repair of the assets. At the time of writing the Operations and Maintenance system is still at an early stage of development. This is principally due to the wind turbines largely being within the warranty period from the manufacturers. The manufacturers have responsibility for the turbines during the warranty period – this is typically for the initial 5 years. Currently half of all turbines installed are less than 6 years old.

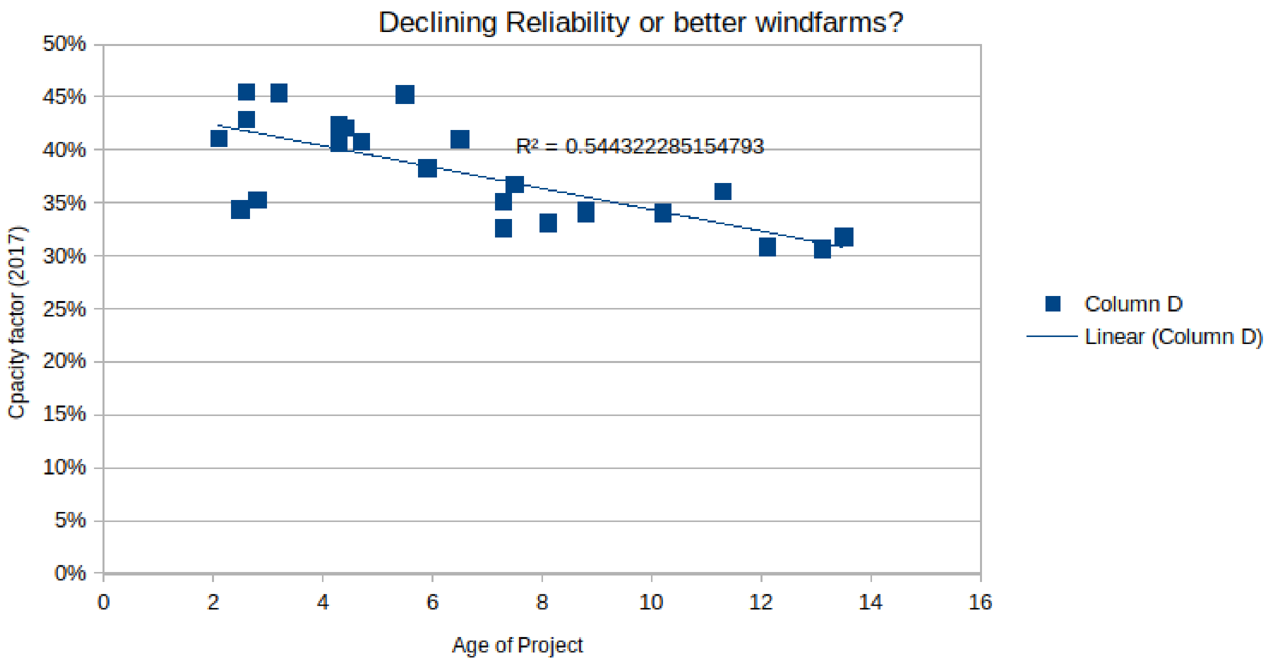
Figure 4.22: Cumulative number of turbines in operation



As Carrol et al identify in their 2016 paper (Carrol, 2016), the relative concentration of wind turbine manufacturers (Siemens-Gamesa and MHI Vestas have a combined market share of 86% of the grid connected offshore wind turbines in Europe in 2018 (WindEurope, 2018)) means that availability and maintenance data is highly commercially sensitive.

Data is available for the capacity factor of offshore wind turbines, giving some indication of effectiveness of offshore operations (Energynumbers.info 2019). This is shown in figure 4.23 below.

Figure 4.23: Capacity factor of Offshore wind Turbines in 2017



The data is suggestive of declining equipment effectiveness as wind farms age but this apparent correlation must be treated with caution. Firstly the correlation is not strong ($R^2 = 0.54$), in fact the pattern could be equally seen as 2 populations of wind farms with different average load factors (those up to 7 years old averaging approximately 40%, those over 7 years old averaging 33%).

Secondly there are a number of known confounding factors that will impact the figures:

- Incremental advances in turbine technology improve the load factors
- Later project sites are in areas of more favourable wind resource
- Earlier sites (especially round 1) were intended to be more experimental and this may have an impact on load factors

Comparison with the greater experience of onshore wind load factors may give some insight. Unfortunately this data (load factor of onshore wind farms by commissioned age) is not available due to the large number of small projects (1645 operational projects with an average of 4.4 turbines per project - source RenewableUK wind energy database), and their diverse ownership (many are farms and/or community-based). The latest government figures do give an annual capacity factor for all onshore wind farms of 28%, demonstrating that the oldest offshore wind farms still meet the goal off substantially higher load factors than onshore (BEIS, 2018a).

It was recognised from the start that offshore wind would present unique challenges, particularly around access with severe restrictions on boat to turbine transfer occurring during poor sea states and poor weather. Aerial access via helicopters is similarly challenging. (figures 4.24 and 4.25 illustrate)

Figure 4.24: Crew transfer to a mono-pile foundation wind turbine from sea

Figure 4.25: Crew transfer to a wind turbine from helicopter

As the scale of offshore operations and maintenance grows, sector specific technologies are developing to provide ‘better’ solutions:

- ‘Walk to work’
- Shorter transfers (from ‘floatels’)
- Access in a wider range of sea conditions

There are also technology solutions to increase availability such as improved condition monitoring and failure prediction, and revised turbine designs to enhance reliability. As identified above, such developments are highly commercially sensitive at this time.

4.4.7 Summary

The six differentiated ‘human activity systems’ occurring within the offshore wind power activity can be seen as processes with a variety of levels of performance that can be assessed somewhat objectively (i.e. arguments are over the underlying meaning of objectively agreed numbers).

Some of the systems have performed better than expected – the innovation system achieving a target LCoE years early is particularly highlighted; others have proved to be less concern than initially expected (finance); and some have proven to be unexpectedly problematic (Scotland’s planning system). This breadth of performance shows that it is important to consider the whole picture to gain an understanding of how a system is performing – the answer is not a one dimensional bad to good.

Given the interest in the emergence and viability of offshore wind power, it is the maturity and effectiveness of the individual sub-processes that comes to the fore. A summary assessment of the maturity and effectiveness of the various sub-systems discussed above is presented in table 4.21 below.

Table 4.21: Sub-system Effectiveness and Maturity

Process	Effectiveness	Maturity
Planning	Effective – sites get consent	Mid level – some issues resulting from change, now dealt with(?)
Finance	Effective	High level – broad range of investors and instruments, cost of finance reducing
Market	Mixed effectiveness – consented projects without a route to market	Mid level – significant backlog of consented projects with no route to market
Innovation	Effective – met goals early	Mid level – limited range of innovation investigated
Installation	Effective – sites get built	Mid level – limited evidence of learning benefit from increased experience
Operations & Maintenance	Mixed effectiveness	Low level – limited experience

The next section reviews the observations of offshore wind power conference and the semi-structured interviews conducted with industry participants.

4.5 Observations & Interviews

4.5.1 The Offshore Wind Power Supply Chain Conference

ScottishRenewables (SR) is a membership organisation that seeks to be *'the voice of Scotland's Renewable energy industry' (*ScottishRenewables, 2018). It has over 200 (208 at the time of writing) business, academic and government organisations as members, roughly a third (77) of which identify as being involved in offshore wind power as opposed to other renewable energy technologies.

In January 2010 SR organised the first Offshore Wind Conference and Exhibition. This conference has been run annually since and is the largest event for offshore wind power focussed organisations in Scotland. The engagement at the conference (from exhibitors and delegates) and the content of the conference sessions provides a series of snapshots of the industry's development over time.

The following data have been collected as a consequence of attending the conferences in all years excluding 2016 and 2018. Data from the years not attended has been obtained from the ScottishRenewables website.

Participants - Exhibitors

The conference started out located in Aberdeen – home to the marine engineering expertise of the oil and gas industry. Since 2016 the conference has been held in Glasgow. This is a reflection of the location of developers such as SSE, SPR, Mainstream and SDIC.

Over the years the event has seen a marked variation in the numbers of exhibitors and the number of delegates at each conference. Figure 4.26 below shows the number of delegates and exhibitors at each conference (excluding the first in 2010 which was before the research started).

Figure 4.26: Exhibitors & Delegates at SR conference by year

It is striking how the number of delegates and exhibitors correlate. To an extent this is under the control of the conference organisers who size the number of places and exhibition space.

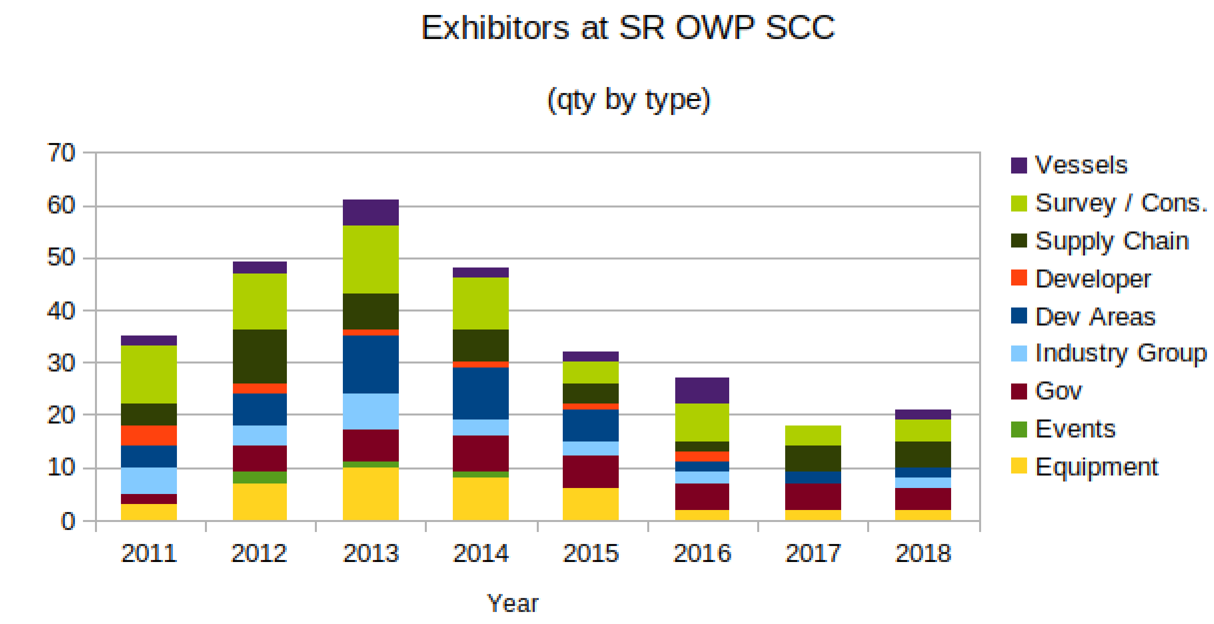
The organisations taking part in the exhibition can be loosely categorised into the following types:

- Development Areas: Organisations seeking to attract commercial activity to their geographic location e.g. Invest in Fife *(secondary)*
- Developer: Organisations bringing offshore wind power generation projects to market e.g. Mainstream Renewables *(primary)*
- Equipment: Organisations offering equipment to offshore developers (to design in) or to the supply chain for use in construction e.g. Aggrekko *(secondary)*
- Events: Organisations promoting other events of interest to industry participants e.g. AllEnergy *(tertiary)*
- Government: Organisations directly funded by, or part of, a national government (either of the United Kingdom, or other nation) e.g. Marine Scotland *(primary & secondary)*
- Industry Group: Organisations representing groups of businesses within an industry e.g. Aberdeen Renewable Energy Group (AREG) *(primary)*
- Supply Chain: Organisations directly involved in the construction of offshore wind projects e.g. Senvion wind turbines *(primary)*
- Survey / Consultancy: Organisations offering consultancy services to offshore wind developers. In early years a large proportion of these organisations were offering survey capability e.g. ornithological survey. *(secondary)*
- Vessels: Organisations involved in providing vessels to the industry through leasing of existing ships and building specialised vessels (e.g. for operations & maintenance access) e.g. GeoSea *(primary & secondary)*

The designation in brackets relates to the primary, secondary and tertiary levels of industry as described in section 4.2 above.

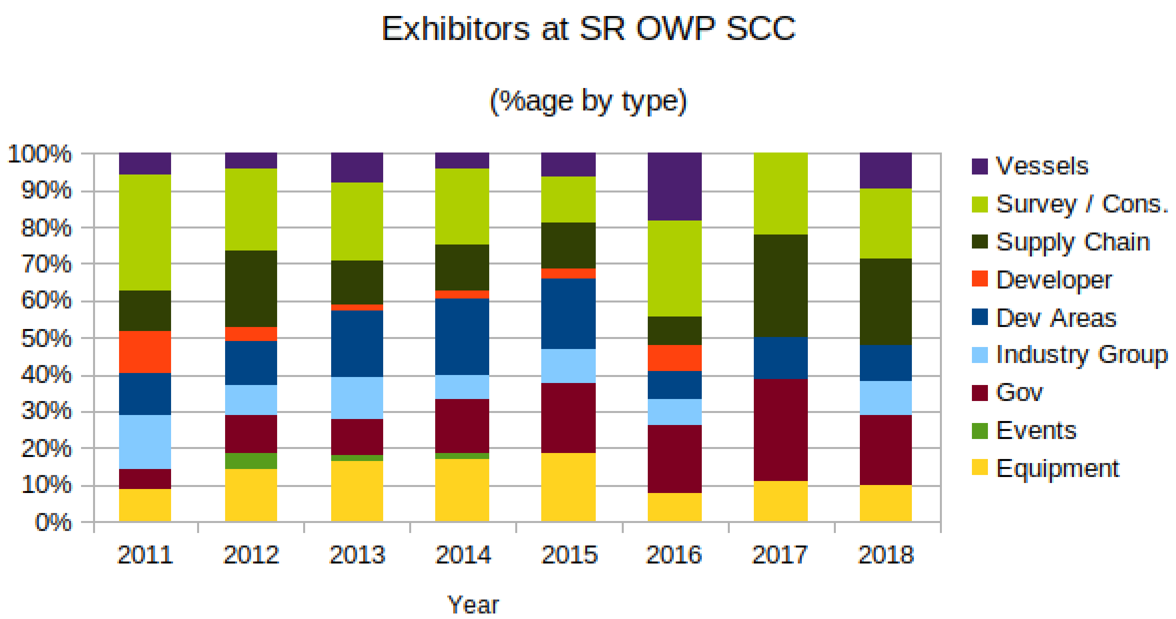
Figure 4.27 below shows the number and type of organisations taking part in the exhibition element of the conference.

Figure 4.27: Chart of Exhibitors at ScottishRenewables Offshore Wind Conference & Exhibition



The different make up of the conference exhibition can be more clearly seen from reviewing the proportion of exhibitors from each category. This is shown in figure 4.28 below.

Figure 4.28: Proportion of Exhibitors by category



These charts show that at least half of the exhibitors have been organisations directly working in offshore wind (or seeking to). Surveying services and consultancy (Survey / Cons.) is consistently among the largest category of exhibitors with the supply chain exhibitors and development areas also figuring. It is notable that the developers do not exhibit at the conference despite being at the core of the industry.

Also apparent is that the growing involvement of government organisations (e.g. Scottish enterprise, Marine Scotland) happens as the involvement of industry bodies (AREG, Renewables UK) drops off.

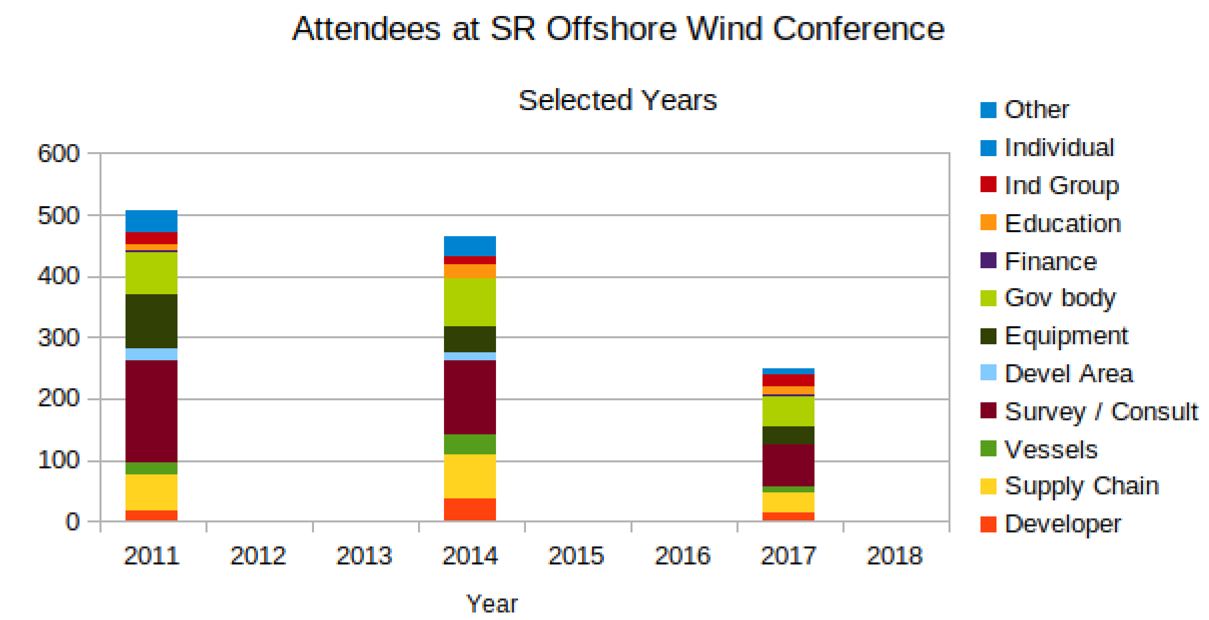
Participants - Delegates

A similar categorisation can be made for delegates at the conference as follows:

- Development Area: as above
- Developer: as above
- Education: Attendee from an eduction organisation including private sector organisations (e.g. Clyde Training) and public colleges, universities etc.
- Equipment: As above
- Finance: Attendee from a financing organisation
- Goverment: As above
- Industry Group: As above
- Individual: Attendee has no specific affiliation
- Other: Attendee is from a non-categorised organisation (this category includes press)
- Supply Chain: As above
- Survey / Consultants: As above
- Vessels: As above

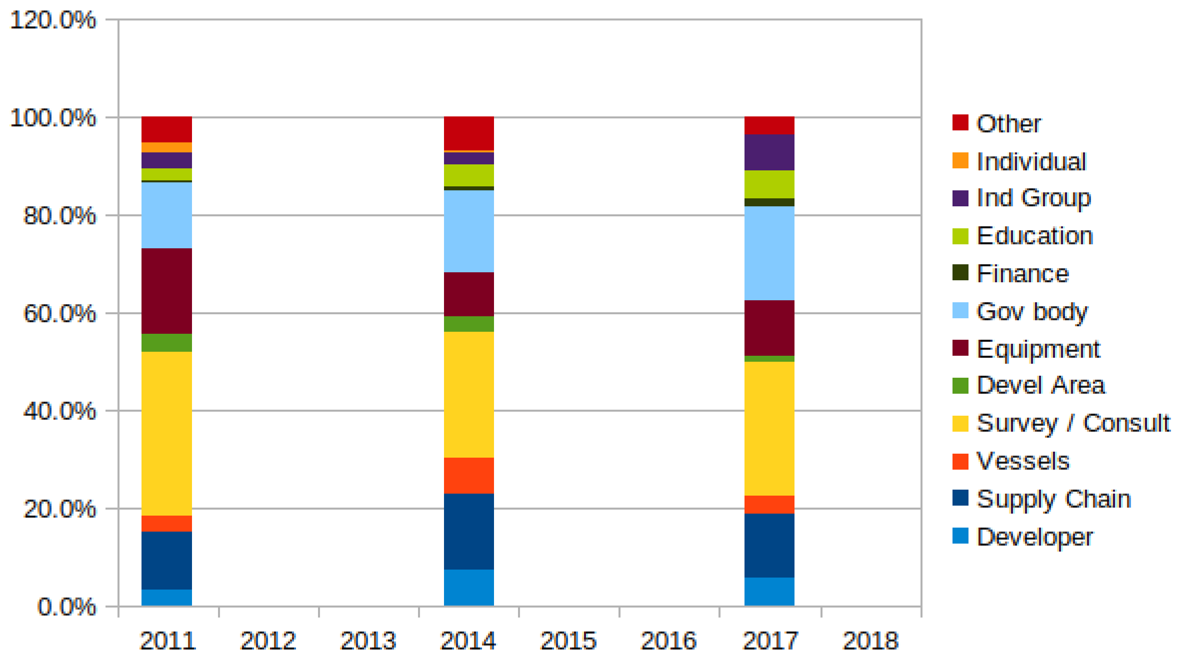
With an order of magnitude higher levels of attendees compared to exhibitors, the following chart plots attendee source from a selection of years only. (see figure 4.29 below)

Figure 4.29: Chart of Attendees at ScottishRenewables Offshore Wind Conference & Exhibition



As before, the large variation in attendees somewhat obscures the make up of the audience. Figure 4.30 below shows the proportion of delegates from each category.

Figure 4.30: Proportion of delegates from each category



This chart shows a relatively stable make up of the audience at the conference over the years with delegates from surveying and consulting firms making up the largest single group, and supply chain and equipment firms also showing strongly. Although a smaller group, the developer organisations do provide a fairly constant proportion of the audience of the conference.

The make up of the delegate and exhibitors underscores that the conference is a forum in which the nascent offshore wind industry gets together.

Content

The scale of the conference content has also changed over the years. The conference was originally held over two days, the programme was shortened by a day in the year (2016) the conference moved to Glasgow. For 2019, the conference programme is expanded to a one and a half day programme.

The summary programme for the annual conference is shown in Table 4.22 below:

Table 4.22: Sessions per conference

Year	AM Day 1	PM Day 1	Eve Day 1	AM Day 2	PM Day 2
2011	Plenary 1 Presentations	Presentations Plenary 2		Plenary 3	Presentations
2012	Plenary 1 Plenary 2	Presentations Plenary 3	Reception	Plenary 4 Presentations	Plenary 5
2013	Plenary 1 Presentations	Presentations Plenary 2	Reception Meal	Plenary 3 Presentations	Plenary 4
2014	Plenary 1 Presentations	Minister Address Plenary 2 Presentations	Reception Meal	Breakfast Plenary 3 Presentations	Plenary 4
2015	Plenary 1 Plenary 2	Presentations	Reception Meal	Plenary 3 Presentations	Plenary 4
2016			Reception Meal	Plenary 1 Presentations	Presentations Plenary 2
2017			Reception Meal	Plenary 1 Presentations	Presentations Plenary 2
2018			Reception Meal	Plenary 1 Presentations	Presentations Plenary 2

The content of the various years' conferences are summarised in the table 4.23 below.

Table 4.23: Programme Content of Conference by year

Year	Presentation Topics	Plenary Sessions
2011	Development Consent & licensing Engineering design & project management Technology Grid Heath & Safety and Skills Operations Emergency response	Ambitions & knowledge transfer Lessons & opportunities cross-sector Update on OWP dev't in Scotland

	Substructures & foundations Operations & Maintenance Design & Consenting studies Electrical Systems Installation Turbine	
2012	Innovative Solutions Accessing the Grid: 1 network Managing the Marine environment – policy Finance – EMR Accessing the Grid: 2 Managing the Marine environment – debate Operations & Maintenance Cost reduction Skills	Spreading the story Closing the Gap(s) Project Updates O&M solutions Securing finance
2013	Cost reduction Delivering Infrastructure Finance landscape Innovation catapult Skills Grid – Coordinated networks Internationalising supply chain Environment – from Precaution to proportionate Heath & Safety	The story so far Projects Update The Build-out story Engagement
2014	Delivery of first projects Offshore transmission regime Procurement – Alliances Scenario mapping Infrastructure – secure benefits Engineering solutions	Concept to reality Project Updates Securing Right investment Global outlook

Year	Presentation Topics	Plenary Sessions
2015	Maximise Supply Chain opportunity Financing Offshore Wind Innovations in Tech Outlook for ports Consenting challenges CfD – what next	Offshore wind in Scotland – new era? The future of the OW industry Cost reduction challenge
2016	Reducing Costs Now Reducing Future Costs Pathways to deployment Facing the Financing challenge Operations & Maintenance Solutions Working with the environment Licencing update	Collaborate & Communicate Successful even if it doesn't feel it
2017	Planning & consent Innovation & Cost reduction Infrastructure & supply chain Innovation & cost reduction	Welcome Industry leaders debate
2018	Optimising Performance: Maximising the Existing Offshore Fleet Planning for Success: A Consenting Framework Fit for Purpose? The Wind Farms of the Future A Competitive, Sustainable Scottish Supply Chain: Performance, Risk and Efficiency Getting Steel in the Water: Project Updates	Building the Future: Carbon, Cost and Competitive Technology

The topics can be coded to the sub-systems for offshore wind power as general topics:

- Planning System
- Financing System
- Innovation System
- Market System
- Installation System
- Operations & Maintenance System

Note: This coding formed part of the analysis that led to the sub-systems described in section 4.4 above.

Table 4.24 below shows which of the sub-systems were the subject of specific presentations in each of the years.

Table 4.24: Number of presentations by Industry Sub-Activity

Topic	2011	2012	2013	2014	2015	2016	2017	2018	Total
Planning	2	2	1	0	1	2	1	1	10
Financing	0	1	1	0	1	1	0	0	4
Innovation	4	2	2	1	1	2	2	1	15
Market	0	0	0	2	1	0	0	0	3
Installation	4	3	5	3	2	1	1	2	21
O&M	2	1	0	0	0	1	0	1	5

The plenary sessions are not included in this analysis as they cover the industry as a whole without any particular focus on industry activities. They do however contribute to the qualitative understanding of how the industry perceives its situation.

Industry 'Mood'

The offshore wind supply chain conference provided the opportunity to observe the industry interacting with existing and potential future members. The detail of who attended and what was presented are shown in the sections above. The events also provide an opportunity to gauge the 'mood' of the conference. It was striking that there was a definable industry 'mood' at each of the annual conferences attended. This is also identified by one of the interviewees (see section below), reinforcing that this 'mood' is not solely an artefact from the observer.

The following table (table 4.25) identifies the mood in each of the conference years and shows the drivers that were highlighted during presentations and in question and answer sessions during each conference that contributed to this.

Table 4.25: Offshore Wind Industry mood as observed at the annual SR conference.

Year	Mood	Explanation
2011	Enthusiasm	Huge potential in the industry Scottish government commitment Can see it can be done
2012	Optimism	Scottish development beginning to happen Consents coming through Contracts (to supply chain) starting Optimistic project round-up
2013	Concern	EMR too slow, too unclear What is UK government commitment after 2020? Capacity in the supply chain
2014	Worry	Cliff face coming, consents taking a long time Real slow down in investments No Scottish FID CfD awards
2015	Pessimism	Conference visibly quieter Key suppliers leave sector (SSE) Lack of UK government 'ambition' CfD awards half volume expected
2016	Depression	RSPB appeal against Firth of Forth projects upheld No construction started in year BEIS replaces DECC
2017	Realism	RSPB appeal overturned in court FID for Beatrice (£2.6B value) See a route to a sustaining industry
2018	Belief	CfD projects bidding low strike prices (<£70/MWhr) German & Danish 'subsidy-free' projects Series of CfD auctions committed to by UK Government

This changing mood is common with many learning and change processes, and is often seen and documented on in single organisations (see Kotter and Schlesinger, 1989 for an exploration of these drivers). The important facet in this research context is that the industry is sufficiently cohesive to have a common mood. It is interpreted as an important indicator of the emergence of the industry as a distinct entity.

4.5.2 Offshore Wind Power participant interviews

Early in the research a number of unstructured interviews were held with participants in the industry to get a sense of what they saw the routes into the industry to be and how they hoped the industry would develop:

- Andy Macdonald (SE)
- Willie Dawson (3Sun)
- Ken Moran (Wood Group)
- Alan MacAskill (Sea Energy Renewables)
- Peter Hughs (Scottish Engineering) / George Kennedy (Castle Precision)

These early interviewees represented their own specific views and covered the broad landscape of the industry – construction manpower, government support agency, independent developer and engineering firm. No direct analysis is taken from these conversations but they helped shape the early interaction with the industry.

A series of interviews were held in 2017 and 2018, with participants from primary and secondary groups of industry organisations. Interviews were conducted on the basis that the outputs would be anonymous, and that the views expressed were the individuals' and not a corporate view. To preserve this anonymity the interviewees are randomly assigned a letter (see table 4.26 below).

Notes from the interviews are collated in Appendix I. Any references to specific organisations or projects that might identify the individual are redacted in the publication version.

The findings are split into the following levels, consistent with Yin's case study method (Yin, 2009)

- Level 1 Analysis: Interviewee responses to the question topics
- Level 2 Analysis: What the responses indicate about the underlying case questions
- Level 3 Analysis: What consistent patterns exist across the interviews
- Level 4 Analysis: Integration with the timeline and sub-systems review data set
- Level 5 Analysis: Normative questions about policy recommendations and conclusions – also covered in the discussion chapter.

The interviewees involvement of and experience in offshore wind power activity is characterised in table 4.26 below

Table 4.26: Interviewees role and experience

Label	Organisational Role	Experience with OWP
A	Current senior policy role within Scotland for a multi-national utility. Previous role within a renewable energy industry body.	Over 10 years experience looking at OWP as a part of portfolios (both in the industry body and the utility) covering all renewable energy technologies.
B	Senior civil servant role within the Scottish government leading the administrations aspirations to benefit from renewable energy.	Over 7 years experience engaging with public sector and industry players within Scotland to maximise the environmental and economic benefits.
C	Current senior role in an industry / academia linking organisation supporting the innovation processes for offshore renewable energy Previous senior role within a UK utility with a strong focus on renewable energy generation	Initially a policy role within the utility then expanded to roles within the industry bodies in Scotland and UK wide. Involved in the UK based cost-reduction task force then deeply involved in what is required to make an industry of offshore wind power.
D	Currently owner of an independent OWP developer. Previous roles in developing offshore wind projects prior to selling on to utilities. Closely involved with industry bodies in OWP.	Involved in offshore wind power since 2001 while at an Oil & gas organisation. Developed early technology demonstrator site, followed by a commercial scale project. Now working on the next generation of innovation in the industry.
E	Current project manager for a Scottish Territorial Waters offshore wind power development led by an independent developer. Previous roles in offshore projects for the oil and gas industry.	Joined the project in 2010 from oil and gas. The expectation was to complete the project and build a pipeline of future projects. The original project had not reached financial close at the time of interview.
F	Currently involved in an consultancy capacity to firms within the OWP industry. Previously held a senior role within a renewable industry body.	Role is to campaign for the optimal legislative, regulatory, financial framework for the growth of renewables in <territory>. OWP is one of 4 to 5 key sectors.

Level 1 Analysis – interviewee responses

Views on the Financing aspect of OWP

The following table summarises the main content of the interview discussion for each candidate.

Table 4.27: Interviewee Responses on Financing

A	B	C	D	E	F
Impact of ROC moving to CfD	Financing & subsidy go together	Scale difference to onshore big factor	ROC v. CfD - People complain about change	Impact of CfD on timing of finance decisions	Early on distinct models for different developers
Big organisation focus	CfD change significant impact	Big organisation fewer projects	If you accept subsidy, government sets the rules	Strong appetite for finance of projects with CfD	No single model for funded development
Consent = finance	Mix of on balance sheet & project finance	Scale on balance sheet risks company	External finance took time to get comfortable with projects – very different from O&G	Less appetite to develop (finance) greenfield sites	Finance never an issue from finance side – just needs good projects
Cost of development	Has become a complicated picture over time	Fledgling thing / changing as it grows	Early (small) projects done on balance sheet – round 1	Projects see changing patterns of investors	Pension funds involved
	Organisations re-cycle their funds	Pre-construction investors (risk+) cf post (pensions)	Larger projects needed Project Finance (external)		Now assets bought & sold at all stages
		Worry early but not been a problem	Latest venture (floating) has a different philosophy. Build as a capability demo on balance sheet and then sell whole project		No longer businesses looking for finance, now finance looking for opportunity
		Planning delays & finance a feature (cf O&G)			

The following common themes were expressed by 3 or more interviewees:

- The impact of the change in market support was significant
- The need for different finance approaches – both on-balance sheet and project finance

- The financing activity has changed over time – some suggestion that the picture is getting more complex

The following themes were discussed by at least 2 interviewees

- More a big organisation thing than onshore wind
- Financing took some time to get ‘moving’
- Finance was a worry ‘early on’ – taken to mean for Round 1 sites – but turned out OK
- Re-financing at different stages is now (in 2018) a feature of the industry

The following were individual comments that give a broader view of the financing landscape and aren’t contradicted by other inputs.

- There is limited appetite for financing ‘greenfield’ sites, i.e. where no development actvity has yet taken place. This implies such work can be expected to be an ‘on-balance sheet’ investment. This is likely to be in the order of £100M, placing some limits on the size of players that can be involved.
- The scale of investment required for offshore wind power is a defining feature of the industry. Note that offshore sites are an average of 52 turbines and 213 MW capacity while onshore sites have an average of 4.3 turbines and 7MW capacity [UKWED @ 10/12/18]. This disparity will grow as more Round 3 sites are constructed (Round 1 sites were limited to 30 turbines and a number of single turbine ‘demo’ sites are included).
- Finance was never an issue from the finance side – it just needed good projects. While there were concerns from developers about being able to access the finance early in the industry development, the finance markets were willing to support projects that produced the right returns.

There were no comments that directly contradicted each other, however one developer’s view of the subsidy regime (‘you just have to get on with it’) was less negative than the general view that the change had been problematic (consent IS finance, finance is easy IF you have CfD, high cost of development prior to CfD).

A secondary industry tier interviewee also identified that the CfD regime was ‘irresistible’ in that it was not possible to argue against the logic of letting a market set the level of subsidy necessary to get investment.

Views on innovation in offshore wind power

The following table summarises the main content of the interview discussion for each candidate.

Table 4.28: Interviewee Responses on Innovation

A	B	C	D	E	F
Success in scaling WTGs	Clunky tech early on	Built from low innovation culture of utilities	Worked well! WTG size has gone beyond expectations	Has worked amazingly well – size of WTGs	Driven by bigger turbines
Next innovations to be proven	Accelerated in last 4 years (WTG size)	Change from innovation IS risk to innovation TACKLES risk	Not bespoke tech – serialised but not mass-manufacture	Innovation a huge part in accelerating industry	Cost reduction a big success
Deeper / further	Driven by experience	Big innovation is WTG scale	Innovation HAS to be stepwise (incremental). Scale builds slowly	Was very much collaborative	May have happened anyway (without institution support)
Electrical connection (reference to HVDC)	Progression of foundation technology	Needs flow of projects to keep innovation going	Economy of scale comes serially – one project after another. Only Dong able to do this at the moment	CfD has stopped collaboration	Move to CfD has been TRANSFORMATIVE on costs
Wider Energy Industry innovation link (Shetland connector)		Confidence in longer term gives confidence to invest in tech	Next big change when WTG scale makes construction hard (125m rotor height)	Industry was able to get all players aligned	CRTF gave people a target to aim for

(Table 4.28 cont.)

A	B	C	D	E	F
CfD reduced collaboration changed innovation		So far it is the WTG. Having built credibility can move on to wider innovation (tip to terminal)	Floating could be like FPSO – can be moved where required. Life beyond the project. CapEx reduced per project	Looking forward – joint action has been eroded	
CfD less information flow e.g. real LCOE		Don't change dominant design while establishing			
No one wants to be first (O&G feature)					

The following points were identified / supported by 3 or more of the interviewees:

- Innovation successfully grew turbine size
- Cost reduction had been a big success from this activity
- CfD introduction reduced levels of collaboration

At least 2 of the interviewees commented on;

- Good level of collaboration across the industry.
- The industry was able to focus on one area of innovation (ever larger turbines reducing the number required to install).
- Still a lot of scope for innovation in future. Foundation technologies were picked as an example.

Comments from individual interviewees that gave additional insight into the industry included;

- Utilities had a low innovation culture. The historical background of the utilities gave them limited exposure to, or appetite for, innovation. They needed to move from an intuition of innovation equals risk, to seeing that innovation helps tackle (and reduce) risk.

- Innovation had to be incremental – economies came from scope more than scale i.e. getting improvement relied on experience from each wave of projects (within rounds – almost by year?) leading to improvements for the next round.

There was some contradiction, or at least different views, on the impact of the shift to CfDs. 3 of the interviewees felt that innovation was hampered by the reduced collaboration of a more competitive environment but one interviewee felt the CfD regime had had a very positive impact on cost reduction action.

Views on planning activity in offshore wind power

The following table summarises the main content of the interview discussion for each candidate.

Table 4.29: Interviewee Responses on Planning

A	B	C	D	E	F
Leasing was naive – no idea what is at sites	Early rounds, sites were just plonked down	Lack of ‘true knowledge’ early on	Scotland incompetent	RUK process worked	Planning system not equipped to deal with the projects
Cf Danish developed sites	With knowledge learned would pick different sites	Precautionary principle threw burden on developers	England competent	Scottish system failed	Took a lot longer than expected timescales
Judicial review = failed planning	Future process to identify ‘better’ sites	Scottish planning system failed	Scottish system has negatively impacted industry in Scotland	PINS (RUK) is rigourous and transparent	Did developers understand the need for a robust system?
	Started v. early with understanding technology		Grid has big impact on sites, has an impact on planning	Planning & CfD interlink extends timescales	England v. Scotland. People judge the system on the result they got rather than the process – that is wrong.

(Table 4.29 cont.)

A	B	C	D	E	F
	Knowledge gained is going around the world				
	Process dictates a lot of money input before the win				
	Other countries may be more attractive to companies (Danish model esp.)				

The following points regarding the leasing and consenting activity were identified by three or more of the interviewees:

- The early leasing process was ‘naive’. The sites being offered lacked a logic or supporting information for their selection. This placed additional financial burden on developers.
- The Scottish planning regime was a failure. Its intended goals of a faster turnaround of projects was not met and the resulting consents were challenged.

Two individuals made the following points:

- The Rest of UK planning model worked. It delivered robust decisions and was transparent. It met the timescales indicated to developers.
- Learning from early rounds has been passed to other territories – notably Denmark (where the government undertakes the early site survey work and then offers the sites to the market)

Comments from individuals that give an additional insight into the planning activity include:

- Current process demands a lot of investment from developers before a consent can be applied for
- Offshore developments are impacted by the onshore situation e.g. grid connections and onshore planning restrictions

- The interaction of planning and the CfD process extends development timescales as the delay in gaining a CfD (or a consent) may mean it is appropriate to redefine the site plan e.g. fewer larger turbines to reduce LCoE. This then requires a planning variation.

One of the strongest held views was that the Scottish planing system had failed (all developers agreed) but this was countered by the view that people judged the system on the outcome they got rather than the process itself.

Views on the energy market as it relates to offshore wind power

The following table summarises the main content of the interview discussion for each candidate.

Table 4.30: Interviewee Responses on Market

A	B	C	D	E	F
Overall a good thing (CfD from ROC)	Targets helped show gov't commitment (regardless of mechanism)	Wasn't keen on CfD change. Just a nuclear thing.	Change made money for professional services	People didn't like CfD but it has worked	RO regime built up unrealistic expectations of what could be supported
Compete across technology	Need a stable market (not there)	ROC poor help to small developers	Whatever the system, you live with it if it allows a return	Once you have a CfD it is great	Hard to argue against CfD logic
Not just CfD carbon price floor	CfD rounds NOT clear – UKGov signal	CfD just moved the risk around	As an engineer don't give a damn about LCOE – just want to make a project with a positive income stream	Painful process to get to the CfD	People were comfortable with it until they realised they might not get a contract
Mismatch between communicated aspiration and budget (Spent well before 2020)	Transparency needed to get supply chain and investors onboard	Biggest issue is CfD budget – insufficient to enable all the early projects	LCOE is a mutable number – GIGO	Future opportunities to use OWP differently (make ammonia / hydrogen)	Developments based on RO and felt they'd had something taken away from them with CfD

(Table 4.30 cont.)

A	B	C	D	E	F
Query methodology (use retail price instead for transparency)	CfD forces pace on projects – impacts budget and time contingency	Budget makes the whole market riskier (timing)	Industry will be subsidy free in foreseeable future		
Assumptions about load factors too low…		CfD may have helped overall but early introduction of competition a stumbling block			
		CfD reduced collaboration			

Three or more interviewees expressed similar views on the following aspects of the energy market as it related to offshore wind power:

- CfD mechanism has been a good mechanism overall
- CfD budget and timing is not transparent enough. The supply chain and developers can't predict what will happen far enough into the future.
- The CfD methodology was also questioned, although not from any consistent stand point.

The following points were made by two of the interviewees:

- The Renewables Obligation regime had it's own issues; it was poor support to small developers; it set unrealistic expectations on what was supportable
- The CfD mechanism adds more 'pain' into the development process; through the complexity of the bid; adds another time pressure for the build.
- Going forward the industry will look for routes to market without CfD support; subsidy free generation for some sites; alternative product e.g. hydrogen or ammonia

The energy market reform also introduced two other mechanisms, a carbon price floor and a capacity market. Neither were commented upon by any of the interviewees.

There were no views expressed by interviewees that were contradicted or countered by other interviewees. One interviewee did comment on the validity of the LCoE number as a ‘real’ measure – it is possible to change the number with different assumptions on load factors (the equivalent percentage of time a turbine is generating at full power), operations and maintenance cost and value at end of life.

Have any aspects of the development of offshore wind been missed?

The following table summarises the main content of the interview discussion for each candidate.

Table 4.31: Interviewee Responses on anything that should have been covered

A	B	C	D	E	F
Compared to nuclear, fewer formal structures e.g. WANO	Everyone plays a part	Behaves as a bunch of projects, not an ongoing industry	This is an infrastructure business – will be cyclical	Inter-relation to O&G and other energy production	Crown Estates decision to go for scale early wrong in hindsight
	A great deal of interaction between discussed elements	O&M not properly integrated	Cyclic factors- some are real, some are sentiment	Policy / public / consumer alignment	Lots of early proclamations based on wrong intuition
	Length of projects cf change in PESTEL factors			Tangible support build confidence	
	Skills / people link to O&G				

A number of helpful points are made by interviewees on the features of the offshore wind power activity. None of these comments point to activities not previously identified. One comment suggests a counter-view that offshore wind power is not an industry but is just a ‘bunch of projects’. A different interviewee compares offshore wind to a different power technology to show how other sectors have additional activities that are core (nuclear power and the global safety structure).

Is OWP a successful industry?

The following table summarises the main content of the interview discussion for each candidate.

Table 4.32: Interviewee Responses on OWP as a success story

A	B	C	D	E	F
Yes – there is manufacturing in UK	Yes – mirror onshore but needed support	Yes – cost out	Reasonably successful – will be subsidy free	Proven itself as a global solution for energy	Yes
Yes – not first market but biggest for some time	Credible energy producer	Getting better at building supply chains (developers lacked capability in this)	Intermittency is the next challenge (after subsidy)	Not a success in Scotland too boom and bust	There was a self-reinforcing excitement and Crown Estate drove some of that
Dealt with manufacture challenge	Evolved very quickly	Need to get O&M experience into designs (more wholistic)		Not built a pipeline of projects in Scotland	Less successful with supply chain than ideal
Dealt with regulatory regime change	Future tech challenges – further offshore / deeper / interconnection	Need to improve collaboration over planning		Has gone global to grow	Needed to build capability in serial construction
Could have done better with site leasing detail	Demand growth – maintain or bootstrap	Future tech challenges: further / deeper / foundations			
		Site development – different role (cf Demark)			

All the interviewees believed that offshore wind power had been successful as an industry. Key success indicators were:

- Credible energy source
- Established UK manufacture
- Met (and exceeded) the cost aspirations
- Met challenges of changed support structure, planning issues
- Expected to be a subsidy free technology in 2020's (by 2030)

- Become a global industry, but UK is still the largest user

4 out of 6 interviewees had areas which they felt the industry had not been successful in, albeit without a common thread. These were:

- Leasing site detail
- Interaction between O&M and designs
- Failed to build a Scottish manufacturing industry
- Failed to develop the local the supply chain

Is there a leader in offshore wind power?

Table 4.33: Interviewee Responses on who leads OWP

A	B	C	D	E	F
UK as a country	Dong – Developer	Developers – Dong	Dong – scale not necessarily capability	Dong – but competition coming	Scottish Power
Scottish Power / Iberdrola as a utility	Siemens – WTG	WTG – Siemens / MHI Vestas			Dong

Dong (now named Oersted) was consistently identified as the lead developer for offshore wind power, with Siemens (now Siemens Gamesa) as the dominant turbine producer. Scottish Power Renewables (as a developer) and MHI Vestas (a turbine producer) were also mentioned by 2 interviewees.

Has the ‘ideal’ wind farm been identified?

Table 4.34: Interviewee Responses on ideal wind farm

A	B	C	D	E	F
Not yet, still too much to discover	Not yet – more basic science	<ran over time>	Scale of 500MW, £1B cost	Number of key cost factors given	Not yet

Half the interviewees felt that the ideal offshore wind farm had not yet been identified and there was good agreement over an underlying reason – there was still basic science to learn (e.g. wake effects on turbine layout, interaction with seabed etc.). Two of the interviewees (both developers) identified a number of relevant factors that would make for a good wind farm. One of these identified the perfect offshore wind farm as being on the cliffs of an island.

Asides

In the course of the interview each respondent made comments not directly related to the semi-structured interview that were nonetheless highly relevant to the overall topic. These responses are summarised below.

Table 4.35: Interviewee Asides

A	B	C	D	E	F
The industry has been unrealistic about timescales … lack of manpower / knowledge etc.	Incoming big players (Chinese?) may move things	To build an industry … Just talking to the senior guys interested in the industry. Look at barriers to getting full potential. Wasn't the technology. Issues were scale and delay around the processes that put the projects together.	Danish & German tenders - €50 Denmark. €50 – €60 Germany. CfD free levels albeit Denmark doesn't include (site) development and Germany doesn't include grid.	Timeline for our project (10 years to construct?) NB sold on to Edf Renewables in May 18	The early targets of 40GW by 2020 were un-affordable at 2 ROCs. Should have been easy to see.
Very different to other manufacturing / product industries	2020 target is challenging due to delays from moving ROC to CfD and onshore having no route to market	Could see this was eminently doable – nothing had to be really invented to get cost down.	Believe the German price assumes 13+MW machines	Comment on mood of conferences – 5 stages	There is a global market for this and we are just at the start

(Table 4.35 cont.)

A	B	C	D	E	F
Assets have a long life so need to be risk adverse		Collegiate willingness across all the industry that if we did pull together we could actually achieve all this stuff – working closely with government, working across the supply chain	Lots of panel discussions had well argued, honestly held OPINIONS about what is best. Only ever true for one set of circumstances		
		Lack of competition an issue for any industry. Big boys dislike it as they get the blame if industry 'goes wrong'			

The above comments add to the case 'texture'. They are not analysed together but are used where they support or contradict other findings.

Level 2 Analysis – core questions

The interview structure is designed to provide insights in to the interviewee's understanding of the industry as a whole. Table 4.36 below highlights the implied responses. NB None of these questions are asked directly of the interviewee.

Table 4.36: Level 2 analysis of interviewee responses

	A	B	C	D	E	F
Does the participant consider OWP an industry?	Yes	Yes	Yes	Yes	Yes	Yes
Does the participant recognise the described sub-systems of the industry?	Yes	Yes	Yes	Yes	Yes	Yes
Did the interview cover a complete view of the industry activities	Yes	Yes	Yes	Yes	Yes	Yes
How effective does the participant see the interaction between the sub-systems of the industry?	Some interaction noted. Subsidy mechanism impacts innovation, planning, finance mechanisms	Some interaction noted. Finance and subsidy mechanism	Some interaction noted. Subsidy and innovation			Some interaction noted. Subsidy and innovation
What is the participant's assessment of the health of the OWP industry?	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed

Strong interaction was noted between the market support system (ROCs and CfDs) and the innovation activity. There was also some recognition of a linkage between the leasing element of the planning activity and the nature of the innovation cycles. Whilst the market reform and the finance activity had a direct connection – in that risk was moved around – no feedback from finance to the market system was noted.

Other interaction that were discussed included the *lack* of good feedback between operations & maintenance activity and experience and the design and installation activity. It was postulated that opportunities for improved designs and processes were being missed as a result.

The strongest 'system signal' was that the whole industry had to show it could reach £100/MWh LCoE by 2020.

Level 3 Analysis – consistent patterns

The responses were reviewed to see whether the interviewees held congruent views of the industry and its challenges, or if there were divergent views. The breadth of interviewee backgrounds and roles allows a view on the agreement or otherwise across different sections of the industry.

There was a common view of what made up the offshore wind power industry and its relevant sub-divisions. The strongest agreement was on where the industry has been successful to date (cost reduction).

There was a limited level of divergence around the impact of the market system. Most interviewees felt that it had been a challenge to the industry rather than a help, but others were either ambivalent (if you want the money, you accept the rules) or believed it was inevitable and a useful driver of cost reduction.

The interviewees views on the absolute success of offshore wind power have a geographical component i.e. is wind power successful from a global perspective, national (UK, Germany, Denmark) or region (Scotland, Baltic Sea etc.)? At the global level, there is support for the idea that wind power has successfully established itself and can now grow. At a national level, the interviewees believe that offshore wind power is a successful UK industry. There is some divergence of views whether it has been a success in Scotland – the time taken for STW developments to get to construction drives one view. An alternative view is that it was possible that there would be no OWP in Scottish waters as it was so much harder than in the southern North Sea.

The analysis suggests a general agreement of the performance and behaviour of the industry with some difference of views on specific elements.

Table 4.37: Pattern of common views on OWP

Did Badly	Important but not clear how helpful / hindrance	Did well
• Selection of sites • Phasing of leasing rounds • Building a local supply chain • Collaboration on non-competitive areas (e.g. surveys) • Project lengths (delays)	• Institutional support • Changing national government • Lack of a stream of projects	• Reduced costs • Managed change to CfD support regime • Challenged negative planning outcomes • Developed economic solutions

Level 4 Analysis – relation to the wider data set

The interview responses can be compared to the recorded performance of the different aspects of the industry (section 4.4).

4 of the 6 'sub-systems' can be dealt with in a straight forward manner:

- Financing – all the sites which had a route to market (either ROCs or CfDs) achieved a final investment decision. Despite the identified early concerns about the level of finance required during a financial / economic recession, projects still got funded.
- Innovation – the LCoE target set out by the Cost Reduction Task Force in 2012 (£100/MWhr for projects commencing in 2020) has been met. This has occurred largely through the development and deployment of turbines that are 3 times the size of the first sites and further opportunities for scale are in planning. The success of this innovation is recognised by participants and corroborated by publicly available data.
- Installation – large scale offshore wind farms have been constructed and are in operation. The pace of construction has increased over time with more and larger turbines being installed each year. No interviewees discussed issues with deploying wind farms, but there is the caveat that none were actively engaged in this.

Two areas where responses and wider data need more exploration to reconcile are the planning activity and the operations and maintenance.

- Planning system – the available data suggest that the Scottish system was OK except for a limited number of sites that had 'special cause' variation. The general consensus of interviewees was that the system in Scotland failed. A way to tie the experience and observations together is provided by one interviewee (F) who said people judged the system on the output not the process. Also relevant to the change is that a new process was being developed to deal with a new situation. A combination of these factors will have impacted on the planning outcomes. The industry in the UK may have benefited from having an alternative planning regime in RUK compared to Scotland to keep projects going.
- Operations & maintenance – this element was not a topic for the interview discussions as much of the data is commercially sensitive. One of the interviewees was clear that the lack of learning from O&M being introduced to future project development is a potential problem for the industry. Some work is being done to address this issue by institutions providing a commercially independent repository for O&M experience data.

Level 5 Analysis – questions about policy recommendations

- Despite strong policy stances in Scotland, OWP is only just being deployed due to issues with the (government set up) planning regime. It is not clear to participants whether the slow deployment of offshore wind in Scotland is a failure of policy; or if, in fact, the deployment of any offshore wind in Scotland is a success of policy.
- Institutional support for developing the supply chain has not led to an OWP supply chain in Scotland. It is not necessarily the case that these approaches have been failures. Individual circumstances have had an impact e.g. BiFab and John Robertson's sudden death (see Robertson, 2017) – these cannot be planned for.
- Planning system – change adds risk, is it worth it and can it be mitigated? In this case, one stakeholder decided the planning decision was flawed and that the whole process could be challenged. In terms of policy deployment one can consider did the stakeholder have sufficient input to new system to avoid this? Any *unexpected* outcome of a changed system or process increases the perception of risk.

4.6 Case Conclusions

4.6.1 OWP is a distinct Industry

Before one can legitimately consider the question of industry emergence, there must be some basis for considering whether any given industry is in fact a separate entity. As the literature review makes clear, early writing on industries made the point that industry and market are concepts that are frequently conflated. Technology has also been used as an industry identifier. There is also the strand of institutional theory which points to identity and legitimacy as the determinant of the existence of an industry.

To avoid tautologies around the identity of the industry, it is possible to look for distinctive features that would separate Offshore Wind Power from closely related industries such as onshore wind power, power generation in general, marine energy etc.

The following sections highlight some defensible distinctive characteristics of offshore wind power generation starting with the overall legislative environment in which the industry operates.

Legislative environment

The first element of the legislative environment relates to the ‘ownership’ of the territory on which offshore wind is cited. This is owned and / or managed (by act of parliament) by The Crown Estates and The Crown Estates Scotland.

This in itself could be expected to give some particular identity to the putative industry. This impact is increased by the way in which the Crown Estate bodies have chosen to make sites available to developers – by way of a succession of leasing rounds, each of which has a stated goal e.g. Round 1 was for demonstration of commercial feasibility and sites were limited to 30 turbines each, Round 2 was for commercial scale projects in near shore waters, Scottish Territorial Waters was for sites in Scottish Waters in more challenging conditions, Round 3 was for the full commercial grade projects, leasing large areas in which multiple projects could be developed, Round 4 (due in 2019) has still to be finalised. Round 4 is expected to include provisions for more floating wind sites.

This phased opening of sites for use has had an impact on the development of technologies, with notably bigger turbines being utilised with each round – although this is more an impact of installation time than leasing rules and as Round 2 and Round 3 sites overlap there is a degree of blurring in this.

The following table shows average turbine size and average number of turbines for operational projects from each of the rounds. For Round 3 and STW the average is for sites operational or under construction as at September 2018.

Table 4.38: Turbine Size and Turbines / project by round.

	Average Turbine Size (MW)	Average Turbines / Project
Round 1	3.1	28.4
Round 2	4.1	82.8
Round 3	6.3	130.7
STW *	7.0	86

* Scottish territorial waters shown after Round 3 as construction at these sites started later.

In interviews both the developers and the catapult interviewees commented on the desirability of having a more constant flow of projects to promote learning-based cost reduction, nonetheless the fact that projects were phased was identified as a notable feature of the industry.

A second element of the legislative environment that differentiates offshore wind from other power generation industries is the planning regime. This is most apparent in Scotland where the government revised the planning process and established a new statutory body to address the looked-for new industry of offshore renewable energy. The goal was to have a single body (Marine Scotland) that addressed all the marine stakeholders in order to provide a faster planning process. The planning process in Scotland is the focus of criticism from interviewees but at this juncture its existence rather than its performance is the relevant point. In England and Wales the planning rules that offshore wind developments required to meet were contained within the broader PINS process. However, within this planning regime, a 'one stop shop' was identified to address the specific needs of offshore wind developers.

This regulatory regime has echoes of the 'empty category' work of Edman and Ahmadjian (2017) in that the legislative regime gives explicit recognition to the nascent industry. It differs in that the regulation was put in place after the beginning of industry activity.

The planning regime will be returned to when considering actions that can support the emergence of a new industry.

The treatment of offshore wind power technology in both the Renewable Obligation support regime and in the Contracts for Difference support regime is a third area that provides a distinction between offshore wind power and related technologies. Of particular relevance for the legitimacy of the industry is that the provisions for offshore wind power were implemented after the beginning of the Renewables Obligation regime (in 2002). Initially offshore wind power obtained a single ROC per MWh of electricity generated, in common with all 'renewable' sources – nuclear was excluded from ROCs at this stage. This changed in 2009 to allow 2 ROCs per MWh for offshore wind generated electricity. This banding was applied across a number of 'green' technologies and so it must be acknowledged it doesn't give offshore wind a unique position.

In the Contracts for Difference regime (CfD), a number of technologies were disallowed from bidding for contracts, including onshore wind generation. This highlights that onshore and offshore wind are considered different technologies, if not industries.

A fourth and final element of the legislative environment for offshore wind power generation is in the unique grid arrangements for offshore wind power. Onshore power generation is directly connected to the onshore grid whose overall management is by National Grid Electricity Transmission plc (NGET). This is sub-divided regionally into 3 transmission operators (TOs) for England and Wales (NGET), southern Scotland (Scottish Power Transmission Limited) and northern Scotland and Scottish islands (Scottish Hydro Electric Transmission plc).

Offshore power transmission is provided by competitively tendered offshore transmission operators (OFTOs). The transmission assets that connect offshore wind to the mainland grid are typically built as part of the offshore wind farm development, but are not allowed to be operated by the windfarm owner they are transferred to an OFTO via a competitive tendering process. There are a number of policy goals behind this need, not least the extensive investment required to connect all planned assets to the grid which would otherwise be a UK government responsibility. The German offshore wind industry suffered a significant delay in its growth while grid connection arrangements were resolved.

It is not necessary to identify the effectiveness or otherwise of the OFTO regime to accept that it is another differentiator for offshore wind power as an industry.

Overall, it can be seen that any organisation looking to be involved with the technology of offshore wind power generation has a significant number of legislative instruments to be familiar with, that are either unique to offshore wind or have particular arrangements and requirements for this technology. This provides a strong foundation for considering offshore wind power a separate and distinct industry.

Technology

As is discussed in the literature, the broad term of 'technology' is put forward as a differentiating factor for separating industries. It is arguable that this approach can be misleading – alternative technologies can service the same market and be identified as the same industry e.g. electronic gaming. However it is also reasonable to look for differences in technologies to consider whether a set of product offerings constitute a segment of an existing industry (in this case onshore wind power) or are in fact the seed of a new industry.

In terms of basic design there are indeed a large number of common factors between offshore and onshore wind turbines that bear consideration:

- Upwind configuration: the blades of the wind turbine are on the windward side of the supporting tower in both cases
- 3 – blade rotor: both types of design have 3 blades
- Multi-stage gearbox transmission: both types of wind turbine (at present) have multiple (2 or 3) stages of gearing between the rotor and the generator

As noted by Henrik Stiesdal (then the Chief technology Officer for Siemens Wind Power) in his James Blyth lecture at Strathclyde University in 2014, most of these features are optimised for onshore wind.

The upwind design removes the noise caused by a blade going into the wind shadow of the tower. This is a significant environmental factor for onshore turbines but comes at the cost of requiring active control of the nacelle to keep the blades into wind plus adds the potential failure mode of a turbine blade bending back into the tower.

The number of blades on a turbine is a design decision that optimises cost against power generation for a swept area. A two bladed design often offers this optimum but causes a significant visual distraction when seen from a distance – the brain perceives a flickering as the blades align with the tower. Again such designs are avoided for onshore turbines to meet planning constraints.

Gearboxes are required to speed up the typical rotor speed of 15 rpm to the input speed required by the generator of circa 1,800 rpm. This allows the generators to be lighter and less costly – the generator is one of the major cost items in a wind turbine assembly. The gearbox is however one of the most maintenance intensive parts of a wind turbine – it contains most of the moving parts and is subject to complex loading conditions (from fluctuating winds, vibration etc.). Direct drive solutions are available but are bulky, heavier and more costly. Onshore wind turbines have limitations in the weights that can be lifted by installation cranes that can get to site and trade increased operations and maintenance cost for reduced capital costs.

It is arguable that all three conditions above are not necessarily optimums for offshore wind turbines – rhythmic noises are not as apparent at sea (and who is there to hear it?), siting turbines offshore is at least partly to remove all visual aspect issues, lift limitations are orders of magnitude greater offshore than on – begging the question why are offshore turbines general schemes so similar to onshore?

In the section on the innovation sub-system one of the questions is whether this similarity indicates a failure of the innovation system. This concludes that the focus of innovation was on reducing the LCoE with the aim of hitting an LCoE of £100/MWh by 2020, and that the system has been successful in this. In fact the similarity of turbines between onshore and offshore despite the different operating environments is to be expected given the 'path dependant' nature of industry evolution. As one of the interviewees characterised it *'early offshore turbines were just onshore ones with a life-jacket in them'*.

This development path was important to maintain investor confidence (or reduce development risk – both views are heavily intertwined). Conference attendees would often talk about 'bankable innovations' being more needed than breakthrough innovations. The successful achievement of the LCoE target is achieved in part by reduced risk premiums for the investment funders. The industry is now looking at very different designs for offshore – there are demonstration sites of 2 bladed wind turbines on open framework towers just being commissioned now.

It is now the case that offshore wind turbines are not interchangeable with onshore turbines. The industries have diverged technically into distinct entities. The differing scale dictated by the operating environment is one issue – transporting 60m blades is just possible by road. Offshore blades are approaching 100m length and are only shipped by sea. Similarly the weight of offshore nacelles are beyond the lifting scope of road transportable cranes. This technical divergence is set to continue (particularly through the scaling of offshore turbines) but as the main producers of wind turbines compete in both markets there can be expected to be residual design similarities.

Industry Structure

Offshore wind has a well defined industry structure. It is a good fit for the described complex product systems (CoPS) industry structure where the central drivers of the industry are the system integrators (developers in the case of offshore wind). In early stages of the industry there was much discussion regarding whether offshore wind turbines would become a mass-manufacture item. This viewpoint arose from the desire to greatly reduce the capital costs of machines through mass production.

In such a situation it is possible to imagine that the OEMs (likely wind turbine generator manufacturers for offshore wind) would have the guiding hand for the industry. Large runs of turbines before design modifications would be expected, with wind farm developers making a choice from several competing OEMs to achieve their project goals.

The industry as it stands is different from this. The scaling up of wind turbines has achieved a different mode for cost saving where the large cost of individual units is offset by their large capacity and the reduced number of them required. One interviewee suggested that there was an ideal size of an offshore wind farm of around 500 – 1,000MW and 50 – 80 turbines. This would be a project scale (in terms of units) not notably greater than Round 2 developments.

With this kind of scale per project, and with a limited number of projects reaching financial closure each year, wind turbine production is closely tied to individual projects. Any application of production technique innovation relates to 'serial production' rather than mass production – how to produce a project 'set' within appropriate timescales. The projects themselves are put forward for final investment decisions with 'assumed' turbine scales and costs. It is usually the case that these turbines have not been produced at the time of selection, although underlying technologies (drive train, blades, control systems) will have been proven in test environments.

The role of the developers then is more than a technology (or product) selector, but a technology specifier. This gives a distinct 'flavour' to the activity that helps to further identify offshore wind as a distinct industry.

Comparison to related industries

Offshore wind people have tended to come from 2 closely related industries – either Onshore Wind or North Sea Oil & Gas. It is potentially arguable that offshore wind is in fact not a distinct industry, but merely an offshoot of either of these 2 industries.

The sections above have addressed distinct features in the legislative environment for the putative industry of offshore wind power, its differentiated technology and its particular industry structure. This section seeks to show how the nature of the activities within offshore wind differentiates it from the 2 industries identified as preceding it.

Taking onshore wind in the first instance, the most striking difference is in the scale of the projects. Table 4.39 below highlights the difference in scale of onshore and offshore wind farms (data from the UK wind energy database [accessed 11/2/19]).

Table 4.39: UKWED data on onshore and offshore wind farms

Technology	Installed capacity	Number of Projects	Number of Turbines	Capacity / project	Turbines / project
Onshore	12,844 MW	1,956	7,725	6.57 MW	3.95
Offshore	7,899 MW	37	1,934	213.5 MW	52.3

This table shows that offshore projects are of a completely different scale. The number of turbines offshore and the project size is also skewed down by the restrictions of the early (Round 1) sites to 30 turbines or fewer and a number of single unit demonstration projects (5 off [repd data sept 2018]) which lowers these averages. It is recognised that large scale onshore projects are hampered by the difficulty in gaining planning consent. However, this is part of the picture of legislative difference that separates the industry sectors.

On top of this greater scale of project there is the greater complexity of the installation process itself. The prime installation operations are, rather obviously, offshore – meaning that alongside each task common with onshore installations, there are additional marine tasks in boat handling (position keeping, crew transfers, sea state monitoring) etc.

Offshore wind farms are therefore a significantly different scale of manpower and investment in comparison to onshore.

In contrast, offshore oil and gas projects can be equally large. The recent development of the Alligin field in the Greater Schiehallion area west of Shetland illustrates this. (Figures from Insider magazine article 22/10/2018 and Energy Voice website). The project is expected to require £230 million capital investment. It will require at least a year to get the complex infrastructure in place (2 wells, links to nearby production infrastructure). The planning process was expedited and took 6 months before approval. All the activity is happening 87 miles offshore in deep water.

The first sessions of the offshore wind conference were held in Aberdeen, frequently described as the 'oil capital' and containing a significant mass of marine engineering expertise. The financial crisis also came with a significant drop in the value of crude oil which was expected to make offshore wind an attractive diversification for many oil and gas firms.

Whilst some firms have become involved (e.g. Foundocean, Technip) there has not been the large influx of oil and gas firms anticipated in the early stages despite the value of oil staying 'lower for longer'. One anecdote that may help provide some insight into this comes from an early interviewee. The individual was interviewed while in the role of head of Offshore Wind for a large offshore engineering concern. This person subsequently left the organisation to set up his own company servicing the industry. After the firm suffered cash flow issues while pursuing offshore wind opportunities they pivoted their focus and are now a successful oil and gas focussed operation.

This experience ties in very closely with the literature observation on 'disillusion' causing a firm drop out in emerging industries just as the industry becomes profitable (see Agarwal et al 2014).

This lack of cross-involvement has kept the 2 sectors differentiated, although it is recognised that there are some supply-chain forms who are involved in both industries (e.g. Burnt Island Fabrication).

4.6.2 OWP has emerged

If Offshore wind Power generation can be convincingly shown to be a distinct industry, then the next question is can it be considered to have 'emerged'? As highlighted in the literature review, there a number of 'regularities' to the emergence stage of industry life cycle. They are described as regularities (see Nelson & Winter work) because there is no necessary, causal link between the features and an industries emergence, but they are frequently seen in emerging industries. As

Peltoniemi (2011) makes clear, these observations have been focussed on product based, mass manufacture industries.

In Fixson and Lee 2012, the authors summarise the literature on regularities of emerging industries as covering:

- Technology discontinuity
- Dominant design
- Firm entry / exit pattern
- Sales take off

All of these regularities can be seen to an extent in the offshore wind industry, and almost equally be argued against.

There has been no 'technology discontinuity' that has caused offshore wind to come into being. The Vindeby windfarm in 1991 is arguably the first example of the technology, but there is nothing unique in the individual turbine make-up. There has however been a discontinuity at the core of the industry's birth – the commitment of government to reduce the level of CO_2 emissions and the need for grid scale generating technologies that would do this. It might be argued that this is an equivalent seed for CoPS industries.

The dominant design has been touched upon earlier as a feature of the industry's branching from onshore wind. There is a clear 'dominant design' - a horizontal axis, 3-bladed, upwind wind turbine generator housed in a nacelle at the top of a closed tower structure. A clear part of the value of this configuration has been the reduction in risk for investors in having a recognisable design – despite there being potential performance and operation benefits in moving from this design. The idea of a dominant design signifying emergence can be countered by the observation that there have not been competing designs which the current configuration came to dominate.

It may be that for a CoPS industry, the issue of dominant design is not about competing alternatives being weeded out, but a consensus building amongst the system integrators as to the 'satisficing' solution. A system integrators goal is not to push the boundaries of technology but to collect together technologies that meet the overall requirement of the end customer. In the case of offshore wind, the requirement areas have been project risk, LCoE, reliability.

The normative pattern of firm entry and exit during the industry life cycle is for the rate of firm entry to the industry to greatly outweigh firm exit during the emergence stage. As the industry moves to growth and maturity, the firm exit rate exceeds firm entry and the number of firms involved greatly decreases – the ‘shake out’ phenomena.

Something approaching this can be seen within the offshore wind industry but it differs from the norm described above. If one takes the developer organisations as the core of the industry in which one might see the growth and shake out phenomena appear then the total number is low. They are also split between independent developers (stand alone) and utility developers (part of a power generation and selling company). Some signs of developers ‘shaking out’ has been seen in that a number of the original stand alone developers no longer exist in name, however these organisations have tended to be taken over by utility developers (SeaEnergy → Repsol Nueva Energias UK→ Red Rock Power ltd.).

There has been a move in the developer organisations where organisations such as DONG (Danish Oil and Natural Gas), Statoil (Norwegian state oil company) and Scottish Power (a part of Iberdrola, a Spanish utility) have increasingly focussed on wind power developments and have changed name (DONG is now Oersted, Statoil is Equinor) and / or divested from thermal power generation (Scottish Power is now a wind energy only company).

The final ‘regularity’ is that of sales take off. Again it can be argued that this has been seen with increasing levels of offshore wind being generated as projects come on stream. It is arguable that this is not a sign of sales growth but of government supported plans coming to fruition. A counter-point to this argument is that as the industry successfully met its LCoE goal and bid prices for CfDs dropped, the appetite to have more offshore wind has grown and so more favourable plans for future offshore developments are being announced by government.

As can be expected, the use of regular features to determine the emergence of a CoPS industry does not produce a clear cut picture. Where this framework has been used in previous case studies, the application has been some time after emergence when outcomes are clearer. There are however some aspects of the specific case of offshore wind that can give a clearer indication of whether it has emerged (or otherwise).

One clear alternative view, is that offshore wind is in fact not an industry but is better thought of as a group of related projects. Once these projects are complete the activity will cease. This is not a specious argument as previous ‘new industry’ opportunities have attracted initial investment which has then not been followed up. An example of this (without commenting on whether the example is a separate industry) would be Scottish electronics where a number of plants were established but no follow up investments came to keep them current. While there remain some electronics plants in Scotland, the activity is in decline.

This argument cannot be countered directly – not enough time has passed – but there are some reasons to believe that the industry is more than a group of projects:

- Long term operations: Unlike product industries where there is a significant cost of goods sold and investment is a sunk cost when looking at annual budgets, an infrastructure business like offshore wind has low O&M costs in comparison to debt servicing on an annual basis. The projects need to operate through to the planned end date to provide the necessary return and there is ongoing activity in O&M all this time. At a minimum there will be an offshore wind operations and maintenance industry for installations happening now, for the next 20 years.
- Locally based utility focussing on wind generation: The recent strategic move by Scottish Power to divest itself of its thermal power generation plants and become a purely renewables business (and at the time of writing a purely wind generation business) indicates a belief in an ongoing sector. It is recognised that as Scottish Power is a division of a larger multi-national electricity utility, the move is less consequential than if it was a stand alone business.
- A chain of progressing projects: Offshore wind power has seen a progressing series of projects as a result of the 'Round' structure of leasing by the seabed administrator. At each stage the rounds have been over-subscribed suggesting an on-going interest in the opportunity offered. A fourth round for leases is in preparation despite there still being development potential in the already leased Round 3 sites.

These elements taken together give a strong indication of an industry that is seen to be 'emerged'. There are additional indicators of the emergence of Offshore Wind power in the underlying 'numbers' of the activity.

- Scale: Offshore wind power now generates electricity at a level close to parity with onshore wind. The latest official figures (Ofgen 2018) show that in Q3 2018 onshore wind produced 5.6TWh and offshore 5.0 Twh. With offshore installations growing steadily and onshore development currently stalled due to no CfDs being offered to it, offshore wind can be projected to be the largest non-thermal renewable electricity producer in 2019.

- Investment: Over €35 Billion has been invested in UK offshore wind between 2010 and 2017 (all figures from WindEurope 2017 review). Despite 2017 representing a significant drop in investment (representing a delay in final investment decisions during the transition from ROC to CfD support regimes) €3.5 Billion was still invested. A potentially more important aspect of the financing picture for recognition of offshore wind as an industry is the level of refinancing of assets. This is considered to indicate developers recycling high risk finance for future projects.
- Lead organisations: 'Identity' is one of the factors that literature has cited as a determinant of an industry (see Mezias et al 2010 as an example). All the interviewees identified DONG (now Oersted) as a leading developer in offshore wind, closely followed by Siemens-Gamesa as the lead wind turbine generator for offshore. This level of recognition suggests an industry moving towards stable growth.

A final group of arguments for the emergence of offshore wind power as an industry is whether the industry has met the promise it held out over alternative forms of renewable power generation. Early sessions of the offshore wind power conference identified the following 'promises' of offshore wind as a renewable technology.

- Easier to get planning permission compared to onshore wind: A touted benefit of offshore wind over onshore is that as the windfarms would be out of sight of land, it would be easire to gain consent in comparison to onshore wind. While many of the interview discussions were about the problems of the consenting process the overall outcome of offshore wind projects is that 87% have gained approval. From Roddis et al 2018 the acceptance of onshore wind farms is 57%.
- Better capacity factors than onshore: Offshore wind was developed because it was expected that the quality of the wind resource would be higher than onshore wind (i.e. wind blows more steadily offshore than on). This would mean that for a given unit of installed capacity, offshore wind farms would produce more total energy. The latest UK government figures published by BEIS (July 2018) give the capacity factor for onshore wind as 27.99%, and for offshore wind as 38.88%. This shows that offshore wind generates 38.9% more power per unit of generating capacity.
- Cheaper levelised cost of energy (LCoE) than onshore: This promise was considered a long term potential that would arise from larger scale turbines and higher generation load factors off-setting the substantially higher costs of offshore installation and operation. An industry

report by the Fraunhofer institute (Fraunhofer Institute, 2018) put onshore LCoE in the range €40 - €80 / MWhr and offshore in the range €80 - €140 / MWhr in 2018. With CfD bid prices of €70 for 2022 generation (Hornsea 2 from CfD register) a move to parity is apparent. Currently this is a moot point as the lack of a route to market is stalling onshore wind developments.

Overall there is strong evidence to accept the proposition that offshore wind power has emerged as an industry. It is noted that the industry identity is focussed on producing power from offshore wind to supply to the UK electricity market. It has not emerged as a manufacturing industry. This is not what the aspirations of supporting regional and national government organisations were stated to be. While developers have participated in supply-chain engagement sessions, local content has not been a key focus for these organisations. As the developers are the organisations at the core of the industry, it is unsurprising that it is the delivery of projects at an acceptable cost that has been the success rather than the size of the local supply chain. The inclusion of local content measure in CfD bids is now beginning to address this.

As the work of Klitkou & Godoe (2013) and Edman and Ahmadjian (2017) shows, emergence is possible without necessarily developing the capacity to address future challenges (viability). In the case of Norwegian SolarPV (Klitkou & Godoe 2013) a change in support policy made the industry's future uncertain. The case of local beer (Edman and Ahmadjian 2017), the lack of cohesion in the 'empty category' led to a dissipation into a different sector – craft beer in place of local beer. With the offshore wind power industry established as an 'emerged' industry, the next question to consider is – is it viable?

4.6.3 Industry is viable at the current stage

As intimated above, the viability of an industry can not be assessed by its survival to date. Such views are inevitably dealt with harshly by history; British (owned) ship-building, railway engines, cars and motorbikes provide some cases for consideration where belief in their on-going viability was misplaced.

The systems literature is helpful here in that two of the approaches make specific reference to the on-going viability of a system in focus. Miller's living systems theory identifies a group of 20 processes that need to be functioning for the system to continue to live. Beer's Viable Systems Model provides a framework for assessing and diagnosing systems for 'viability'.While such formal structures are useful for assessing whether a system could be viable, they don't immediately provide an assessment of whether it is viable.

Looking at the case data does suggest a number of indications to support an argument thar offshore wind power generation can be considered viable.

Subsidy free future

The Norwegian Solar PV case mentioned in the previous section (Klitkou & Godoe 2013) shows how a change in support mechanisms can bring a halt to industry activity. In the case of Norwegian Solar PV the support for technology *development* was not matched by support for product *deployment* and during the financial crisis the production part of the industry moved to other countries to be closer to demand.

At the current stage of emergence, offshore wind is also reliant on subsidy mechanisms and is therefore arguably not yet viable. The step change in support mechanism from ROC to CfD coincided with a marked drop in projects coming to fruition while the industry adapted to the implications of the change. This demonstrated the vulnerability of the industry.

The industry can counter this argument (or actual vulnerability) by demonstrating a progressive reduction in LCoE (and so reliance on subsidy), and give examples from other legislative territories that show a path to a subsidy free future. Dutch and Germany auctions have had zero-value bids that propose subsidy-free operation (Hollandse Kust Zuid 1& 2 in Netherlands, OWP West and Borkum Riffgrund West II in Germany). There are differences in the support system and the legislative environment that stop these projects being directly comparable to the UK market (e.g. responsibility for grid connection, pre-development of sites).

As an indication of the support level of offshore wind, the latest CfD auction (third allocation, 2019) has an annual budget of £60 million per annum. This is to support a maximum of 6 GW capacity of energy at strike prices of £56 / MWhr. (Source: CfD draft budget notice 20 November 2018). At a load factor of 50%, 6GW capacity represents 26.28 TWhr of annual electricity worth £1,472 million at the given strike price (the budget is 4.1% of this number).

Even with a notional subsidy-free future envisaged in the late 2020's the industry will remain susceptible to policy change as shown by other markets. Vulnerabilities include the consenting process for re-powering existing sites, availability of new sites for development, support for other renewable technology undermining the market for offshore wind. So while the path to a zero-subsidy future does support the proposition of offshore wind power generation as a viable industry, evidence of the ability to address challenges is also important.

Ability to address challenges

A less ‘fiscal’ view of the viability of offshore wind power generation is to consider what challenges it has met to date. The relevance of this builds upon Ashby’s Law of Requisite Variety (Ashby 1958), and is at the core of Beer’s thinking on a Viable System Model (see Beer 1984 for fuller explanation) – a viable system must be able to generate sufficient variety of response to meet the changing environment it operates in.

The following are some of the challenges that the industry has met during the emergence phase;

- **Installation**: At the start of Round 1 installations there was no experience with installing such large scale structures in volume. There was much discussion in the offshore wind power conference about the need for specialist vessels and the potential for wind farm installation to be a bottleneck on the development of the industry. In the analysis of the installation process it can be seen that there is a small reduction in installation time per turbine (see figure 4.15 above). The increasing project complexity and scale has not impacted this number (or has been balanced by increases in capability). The scope of this research has not involved looking at details of the operations but it can be said that installation is not a focus of concern in the developments now.
- **Levelised cost of energy:** The successful meeting of this challenge has been addressed in earlier sections. It is an important outcome for the industry as it has been achieved through a series of technology, process and finance improvements over the series of leasing rounds. Product – larger wind turbines reduce per unit capacity install costs, taller wind turbines increase capacity factors. Process – optimised installation processes reduce install costs (like for like). Finance – success in these things reduces planned for construction risk, operation experience increases project value to pension firm investors allowing finance recycling and reducing duration of risk exposure.
- **Manufacturing base in UK**: The UK was a late adopter of commercial scale onshore wind. The onshore industry has not resulted in any notable manufacturing capability for the primary components within the UK. Sites such as the towers manufacturer in Argyll Scotland and the blade manufacturer on the Isle of Wight were established for onshore wind but have come close to bankruptcy on a number of occasions. One of the interviewee identified successes for offshore wind is that it has led to a manufacturing base in the UK – the most notable being the Siemens Gamesa operation in Hull, as well as a new focus for the wind towers factory in Argyll, Scotland (now owned by CSWind a Chinese company) and the Isle of Wight blade factory (owned by MHI Vestas).

- **Move from ROC to CfD**: This was a highly significant change in the potential for offshore wind to make the return on investment that would see projects constructed. It came about as the result of a change of government, although with the benefit of hindsight, interviewees said the change was hard to argue against. The change itself took place over a number of years. The energy market Review which formed the background to the change was initiated in 2011 but with the change of ruling party in government in 2015 the final details of strike prices were not finalised until that year. An interim award of CfDs was given in 2014 to bridge between the 2 regimes, before the first auction in 2015. If nothing else the change of support mechanism introduced a high degree of uncertainty to the industry. In the final outcome no projects were abandoned due to the new financial arrangements but a number are delayed awaiting CfDs.

It should also be recognised that the interviewees did identify a challenge to the industry that they felt the industry as a whole had failed to address, that being the marine planning regime in Scotland. This was introduced to be a support to 'good' marine development plans including offshore wind power generation. The intent was to streamline the process and deliver planning decisions within 9 months. In bald terms it has spectacularly failed to achieve this – when a number of projects which were approved under a single consideration, one stakeholder felt this was too impactful on the environment and challenged the planning process. The final result was the process was upheld but at the cost of significant delay. As a counter-point to the negative view of the Scottish planning regime, one interviewee suggested people were judging the process on the outcome they got, rather than the effectiveness of the process.

An integral facet of viable systems is the ability to identify challenges beyond the normal daily operations that affect the system as a whole, followed by actions that make the necessary system changes. In VSM terms the identification of challenges is an 'algedonic signal' and the response is a cascading series of amplified activities to address the challenge.

The successful identification and addressing of challenges is therefore a significant support for proposition of viability in the offshore wind power generation industry.

Maturity of sub-systems

Given a systems view of the industry, it ought to be possible to make an assessment of the emergence of the system by considering the maturity of the sub-processes within the industry-as-a-system.

In the case of offshore wind power generation a series of 6 sub-systems have been surfaced (see the discussion section on industry as a system above). The following considers what measures of maturity might be looked for in each sub-system. It must be underlined that these measures of maturity are considered after observation surfaced the sub-processes and so absence of evidence is not evidence of absence.

- **Market Regulation**: The purpose of this sub-system is to ensure a viable market for offshore wind – this must mean both an affordable subsidy regime and prospects for sufficiently profitable projects as well as the support in the broader policy mix. Maturity measures for such a process are not immediately obvious. Indicators of the process failing would be, on the profitability side, projects closing before final investment decision. Affordability is harder to determine but may be linked to the market rates for electricity.
- **Planning**: This sub-process has the purpose of consenting 'good' projects (acceptable to legal requirements and wider stakeholders) in a reliable time period (for project planning). Measures which can evidence the level of maturity are the proportion of rejected submissions, the proportion of appeals (for and against acceptance and rejection), the length of time in consenting and the predictability of time period.
- **Finance**: The purpose of the finance sub-system is to provide finance for projects at an efficient market rate. The more the market looks like other infrastructure project financial markets, the more it can be considered mature. Indicators of this are the arrival of general (rather than specialist) funders, a mix of risk profile investors and an active recycling of finance as projects progress through risk stages.
- **Innovation**: The innovation sub-process has had a very specific focus on LCoE reduction for the duration of this study. The goal remains pertinent until the industry is operating as 'zero-subsidy'. As discussed above, this may not mean the removal of CfD like price mechanisms, only that they do not require external funding. To be truly mature, the innovation sub-process must be able to change focus e.g. bringing forth technologies that extend the utility of offshore wind, introducing new tools and methods for operations and maintenance, exploring the utility of new technologies)
- **Installation**: The purpose of this sub-process is to efficiently and effectively get offshore wind farms installed and operating. As configured in this analysis, the process includes all the project development, systems design, contracting and installation activities. Maturity in this process will include a level of isomorphism (different supply networks tend to work in

the same way), reliability of time-frames from lease to commissioning, a learning benefit (e.g. time per turbine install reducing).

- **Operations & maintenance**: This sub-process exists to ensure the reliable operation of the generating system at the minimum cost per generated unit of electricity. The achievement of this goal is dependant, at least in part, on the effectiveness of the design, installation and commissioning stages of the 'installation' sub-process. Measures of maturity may include unit reliability, OEE, maintenance cost per unit of generated electricity, mean time to failure / mean time to repair etc.

Assessing maturity is a well developed review technique within management practice. Operationalisation of maturity models is exemplified within the CMMI developed at Carnegie Mellon University. Within its norms it proposes the following maturity levels (see https://cmmiinstitute.com/learning/appraisals/levels):

- Maturity Level 0 Incomplete: Processes Ad hoc and unknown. Work may or may not get completed.
- Maturity Level 1 Initial: Processes unpredictable and reactive. Work gets completed but is often delayed and over budget.
- Maturity Level 2 Managed: Processes managed on the project (case by case) level. Projects are planned, performed, measured, and controlled.
- Maturity Level 3 Defined: Process management is proactive, rather than reactive. Organization (in this case; industry) -wide standards provide guidance across projects, programs, and portfolios.
- Maturity Level 4 Quantitatively Managed: Processes are measured and controlled. Organization (industry) is data-driven with quantitative performance improvement objectives that are predictable and align to meet the needs of internal and external stakeholders.
- Maturity Level 5 Optimizing: Processes are stable and flexible. Organization (industry) is focused on continuous improvement and is built to pivot and respond to opportunity and change. The organization's stability provides a platform for agility and innovation.

Many other maturity models exist, often as developments of the above basic assessment, to support different industry situations. The CMMI levels offer a template to consider the maturity of the industry subprocesses as follows:

- Level 1: Sub-process is unpredictable and outcomes are sub-optimal
- Level 2: Sub-processes are functional but operate on a case-by-case basis (usually project)
- Level 3: Common industry understanding and following of processes
- Level 4: Industry processes (and outcomes) are measured and opportunities for improvement identified
- Level 5: Industry processes are stable and flexible. Learning effects seen industry-wide and new opportunities are surfaced and pursued.

It is proposed here that a maturity of level 3 should be expected of an emerged industry that has moved beyond a project by project focus and is viable in the medium term. The assessment summarised in table 4.40 below is based upon prior captured data and so can only be considered an indication. The formal development of industry process maturity models represents a future research opportunity.

Table 4.40: Maturity level assessment of the industry sub-processes

Process	Maturity Measure	Evidence	Maturity Level				
			1	2	3	4	5
Market Regulation	Affordability of support Financial attractiveness of projects	Reducing value Projects reaching FID					
Planning	Proportion of projects proceeding Consistency of timescales Level of appeals	Percentage proceeding Variability of timescales Percentage of appeals		Sc	E		
Finance	Mix of funding sources Low risk investors Recycling of debt	Organisations involved					
Innovation	Clear goals Ability to define new goals Ability to fund new goals	Reducing LCoE New innovations investigated					
Installation	Commonality of project approaches Effectiveness of installations Consistency of timescales	Length of construction phase Reported delays Project structure					
Operation & Maintenance	Unit reliability OEE	tba		*			

Sc – Scotland; E – England & Wales; * – too early to assess meaningfully

The levels given are intended to show a mixed level of maturity across the industry sub-processes and their relative positions rather than a hard analysis of the industry.

The evidence of effectiveness of the sub-processes supports the proposition that industry has successfully established itself and has a viable platform for growth. The two processes that are lagging (at level 2) have specific addressable causes – in terms of planning, the Scottish system faced a legal challenge to the process which was successfully defended but this impacted the confidence and timescales of the process, regarding the Operations and Maintenance sub-process there is little experience to provide the evidence of maturity beyond level 2.

Future potential

A final indicator for the viability of the industry is the extent to which the future potential and path for the industry can be seen. At the time of writing a total of 7.9 GW of offshore wind has been installed and commissioned. A further 2.5GW is under construction in 3 projects with 'first power' (the first turbines generating electricity and supplying to the grid) coming from 2 of these projects in January 2019. The minimum size of the industry can be considered as 12 GW across 40 projects and 2,300 turbines installed

A further 12 GW of capacity across 15 projects (1300 turbines) has been consented and needs to win a CfD in order to reach final investment decision, so it can be argued that in terms of the industry as it stands, it has only addressed half off its potential (all figures from the UK Wind Energy database maintained by Renewable UK) and there is a clear future leading to 20GW installed. The government has indicated an intention (CfD policy statement) to hold CfD auctions every 2 years through to 2030 to achieve 20GW installed by 2030. It is noted that this does not include any additional projects developed in the already leased Round 3 development areas. There is also some expectation that projects will reach a 'subsidy-free' state within this timescale.

Discussions with interviewees highlighted a broader view of future potential in the industry some aspects of which would require additional (or ongoing) government support.

The first aspect is the move to deeper waters for installation of 'fixed foundation' wind turbines. To date projects have been near shore (less than 30km) and in shallower waters (less than 30m). Round 3 projects move to deeper waters (50m depth and greater) and further offshore. As the foundation designs and installation techniques become proven, the potential for opening up the more extreme development areas increases.

Deeper waters are attractive as they are associated with greater wind resource (steadier and stronger winds). As with oil and gas experience, there comes a depth where fixed foundation structures become impractical. Floating 'foundations' are the technical solution to this and technology demonstrators are already coming forward (Hywind Scotland – operational, Kincardine Offshore Wind – consented, Dounreay Tri-floating wind – consented). Floating technologies are currently more expensive but they offer advantages in accessing the greater wind resource in deep waters (>100m) as discussed. They also have the potential to ease installation and commissioning off very large structures. This potential is being recognised through special arrangements (specific strike price targets for floating wind that are greater than fixed offshore wind in CfD auctions, leasing sites in the proposed Round 4 that suit floating wind).

The above two elements cover the more concrete future potential for offshore wind power. Interviewees also touched on less publically explored areas for offshore wind in the future.

As has been covered when considering industry sub-process maturity, the operations and maintenance activity is comparatively lacking in experience and development. There are developing novel approaches in the known key areas of accessing wind turbines safely and travel time to sites through the development of 'floatels' with a number of companies offering vessels providing combined accommodation and 'walk to work' access for offshore wind. This is a common development with offshore oil and gas.

A number of the interviewees expressed the opinion that there would be significant opportunity and development potential in the area of operations and maintenance going forward. Topic areas touched upon included improved predictive maintenance from big data condition monitoring and remote manipulation / autonomous vehicles for inspection.

Moving into the more speculative potentials, some of the developers discussed 'different downstreams' for offshore wind, i.e. different use of the power generated to maximise the return on investment. Oil and gas firms are already investigating the use of offshore wind generated electricity to reduce the cost of operation of oil and gas production platforms. This sharing of infrastructure may also go the other way. Oils and gas producers are looking at generating electricity offshore using gas that it is not cost effective to export into the gas grid. This electricity could then be exported via the offshore transmission infrastructure constructed for offshore wind farms.

More blue sky ideas suggested for using offshore wind power 'in situ' have included recharging electric propulsion shipping when that comes along and producing energy dense synthetic fuels (hydrogen, methane, ammonia) that are carbon neutral via offshore infrastructure.

The future potential discussed above ranges from the 'will happen' to the purely speculative. What is does evidence is that the industry is actively seeking a broad variety of outlets for its core deliverable – carbon free power. This diversity will help the industry address future challenges within its regulated markets and is another indicator of the viability of the industry.

This section has discussed the proposition that the offshore wind power generation industry is 'viable'. The proposition is supported by the prospect of the industry to be zero subsidy, removing the vulnerability to government funding decisions; by the industries demonstrated ability to address challenges faced in the early stages of growth; by the maturity of the constituent sub-systems; and by the future potential the industry has been able to identify both in medium term concrete opportunities and in more speculative opportunities for diversification.

This review avoids the level of detail required to support the technical assessments using Viable Systems Model and / or Living Systems Theory (e.g. VSM would look for evidence of the contraction of multiple environmental signals into an 'algedonic' signal to the meta-system; LST would seek evidence of an input transducer feeding the internal transducer and decoder that pass information to the decider and so forth). Nonetheless the review does give a grounded view of viability that can be compared with these theoretical constructs.

4.6.4 What actions have supported emergence and viability?

This discussion has limitations that must be acknowledged. It is based on the topics raised by interviewees or observed in the offshore wind power conference presentations and discussions rather than from direct collation and examination of policy instruments and legislation. It is not intended to be a formal policy analysis but to serve as context to such analyses.

The value of this discussion comes from its roots in the experience of industry participants as it develops and emerges. There are specific legislative instruments that have clearly directly led to the industry (Climate Change Act 2008 for example) but that are not in the foreground of actions for the industry participants, and so are not discussed here. Alternatively much is made by interviewees on the visibility of support from individual levels of government – both in terms of their own activities (senior government figures meeting potential inward investors) and in public that have no specific policy instrument. Such are discussed here.

As an example one of the interviewees commented in a discussion about how innovation support had worked;

> *'Would the innovation have happened even without the support? Probably – people are looking for the best turbine at best price then you'll fight to be that. It doesn't hurt to have all that government 'stuff' around but my sense is if you could run it all again it would have happened anyway.'*

This would be countered with a response to the interviewer questioning if the industry was lacking ambition in innovation and hence success was easy.

> *'No we were lucky to get all the ducks lined up. A 'swiss cheese' accident of enthusiasm – policy alignment, government alignment, subsidy alignment, public alignment, industry wanting to set up and also downturn in oil and gas.'*

With alternative, but not contradictory views, as above, it becomes hard to do a rigid analysis of the impact of actions (e.g. policy actions). In systems terms this is to be expected in any case – action (cause) and the full effect of that action are separated both in time and in location; what may seem as an initially helpful action can later be seen to be at root of continuing problems (described as the law of unintended consequences).

To address this, the discussion here is far more qualitative and seeks to examine the views industry participants had about the actions that were undertaken in support of the industry.

The following table sets out the discussed and observed actions that were considered to be external to the industry. These are grouped as facets of support. The table also includes an indication of what positive and what negative impacts were perceived from each of the actions.

Table 4.41: External support actions to the industry and perceived impact

Facet	External Action	Negative	Positive
Crown estates role	Offering sites for lease	Constrains development area Lack of prior development	Single owner Gives legitimacy
	Development Rounds	Constrains development timelines Impacts the flow of projects	Structures development and learning
Energy market reform	Establish ROC for ‘renewables’ (not nuclear)	Sets renewables in opposition to other non-carbon generation	Set financial plausibility Gives legitimacy
	Setting preferential ROC	Sets renewables technologies in opposition	Improves financial feasibility Further legitimacy
	Change to CfD	Uncertainty and delay Reduce collaboration	Spurs cost reduction Affordability
	CfD auctions	Delay	Competitive pressure
	Removal of Onshore & Solar		Offshore is only game in town
Policy	National Govt	Lack of clarity	
	Regional (Scottish)		Legitimacy Focus
	Local (Hull)		Focussed
Related legislation	Marine Planning	New process - challenge and delay	Faster process
Funded innovation programmes	Cost reduction task force		Collaboration Investor confidence Common pathway

The first facet of external support or offshore wind power generation is the role of the Crown Estates (and Crown Estates Scotland) as the owners and managers of all the sea bed in which offshore wind turbines can be sited. To an extent the organisation’s support is entirely binary – if they did not offer sites for development there would be no offshore wind turbines. Leaving that aside as a given, there are a number of actions from the Crown estate that have shaped the development of offshore wind power generation.

The initial location of sites for leasing via Round 1 was left very open, the main constraint was on the size of sites (no more than 30 wind turbines). This meant that while applicants had a great deal of flexibility, there was no information about what was there. All the site conditions had to be determined after leases had been awarded – seabed conditions, wildlife surveys on the surface and throughout the water column, sea conditions (wave heights currents etc.) and the level of wind resource.

The interviewees described this initial round as ‘naive’ and pointed out that leases were awarded for sites that could not have been expected to be awarded planning permission e.g. site straddled 3 busy shipping lanes (Cromer). Because all the sites were covered by a single owner, no development project gained advantage from the process, and no one considered the process unfair. While there is an implicit criticism of the site owner, the broad feeling was that Round 1 was, as intended, a learning experience and that the industry got its ‘kick start’ from the official recognition of potential in offshore wind power.

Later rounds were supported by Strategic Environmental Assessments to identify appropriate sites for development – carried out on behalf of the UK government. This was seen as a positive learning outcome from the Round 1 experience.

Within the context of this study, it is considered that the ownership role of the Crown Estates both helped the emergence of the industry (by increasing legitimacy) and contributed to its ongoing viability (by forcing the industry to address early challenges on site feasibility).

The phasing of leasing into development rounds was intended to promote the on-going development of the industry. It can be argued that this learning can be observed in the increasing size, distance offshore and other complexities of the projects while still maintaining a consistent (or reducing) time per turbine installation rate. There are also apparent learning effects in the England and Wales planning process where variability has been greatly reduced. The impact of introducing a new process in Scotland clearly impacts the learning process. This is discussed later.

The negative impact of the Rounds approach is that it failed to provide a steady stream of projects. Interviewees commented on this as impacting the development of the local (UK based) supply chain. A point of contention at the offshore wind conference was developers not seeing investment in the supply chain and the supply chain pointing out the dearth of contracts being let (and so being unwilling to invest). The Crown Estate addressed this concern between Rounds 2 and 3 by allowing applications for extensions to the existing Round 1 and Round 2 sites to provide an ongoing installations activity.

It is considered that the while the structuring of the development of offshore wind power via rounds is a helpful approach for the emergence and viability of the industry overall, the actual timings and the lack of clarity of how many rounds and when had a detrimental effect on the development of the local supply chain. It is recognised that wider factors also contribute to the development, or otherwise, of the local supply chain (examples are general risk appetite of firms, alternative industries to be involved in and entrepreneurial stance of small firms).

Moving to the impact of the subsidy regime on the emergence and viability of the industry, the response of the industry to the move to a Contracts for Difference regime has been discussed in some depth earlier. This discussion will be limited to how the support impacted on emergence and on viability.

It is clear that without stimulus the industry would not have moved beyond a demonstration level. The first part of this stimulus was the public recognition that existing mechanisms for non-carbon generation had not been successful.

This recognition led to the introduction of the Renewables Obligation scheme and saw the definition of 'renewables' as a category of non-carbon electricity generation. At this point nuclear power was separated out of the support mechanism. This gave a clear signal regarding the comparative technologies for offshore wind (mainly onshore wind, solar and hydro with biomass generation coming later). Early participants could 'see' a competitive position versus onshore wind – not necessarily cost parity, but a mix of potential for greater scale, more reliable (less intermittent) power and greater public acceptability.

Offshore wind was eventually given a preferential rate of 2 ROCs after the majority (11 of 13) Round 1 sites were operational. This was signalled by the government as a recognition that the RO scheme needed to support less mature technologies (e.g. compared to landfill gas and onshore wind) in order to meet the governments legally binding carbon reduction targets. Banding of ROC applied to a number of technologies.

These actions supported (arguably drove) the emergence of offshore wind but may also have been damaging to the future viability of the industry. In 2007 (prior to the introduction of banding) OFGEM questioned the affordability of the RO scheme overall. A change of government in 2010 saw the start of an Energy Market review which also questioned the affordability of the support mechanism for all renewables energy generation. This led to a great deal of uncertainty in the industry and can be argued to have stalled the emergence. At the same time it highlighted the need for a coherent cost reduction effort – one of the major success of the industry in its emergence stage, and a key indicator of future viability.

The introduction of the CfD reinforced the feeling of uncertainty in the industry, both because of a lack clarity on how the funds would be dispersed – while firms were aware that there would be an auction, the capping of support funds and the potential to not get a CfD were not known – and because of a lack of clarity when the auctions would be held – an initial dispersement was made in 2014 to cover the transition from ROCs in April 2017, the first auction was held in 2015 but the follow on auction was not announced until late 2016. At the time of writing a third allocation round is proposed for May 2019.

There is evidence that the growth of the industry stalled at the time the CfD process was being brought to light (no construction commenced in 2015 and none completed in 2016). The mood of the 2016 offshore wind conference was characterised by one interviewee as '*will we build anything?'*. It must be recognised that 2015 was the year that the German offshore wind market resolved its grid connection issues and a large volume of offshore wind was constructed in this market at this time.

The overall impact of the CfD process then, can be argued to have been detrimental to the emergence of the industry due to delay (and therefore likely impact on the supply chain) however it can be argued to have strengthened the viability of the industry by accelerating cost reduction activity through competitive pressures. Some interviewees argue that this competitive pressure was brought in too early, reducing collaboration before large scale projects (Round 3) were under way.

Policy support for offshore wind has been perceived to be strong at both a regional and a local level. The Scottish government has been actively promoting the de-carbonising of the economy and moved from targets of electricity generated by non-carbon sources to targets of all energy (e.g. including transport and heating) becoming non-carbon based. Since 2008 it has been a part funder of the Offshore Wind Accelerator programme (see later in this section). When the Round 2 SEA identified 3 areas suitable for development that were all outwith Scottish waters it instigated a Scottish Territorial Waters round in conjunction with The Crown Estates Scotland. Locally, ports such as Peterhead, Wick, Newcastle and Hull have all been active in supporting incoming investment for offshore wind.

As identified in the interviewee's quote at the start of this section, there has been a strong climate of support for the industry within Scotland. Discussions with individuals did question how effective this had been. Until 2018 there were very few offshore wind turbines connected to the grid in Scotland. Robin Rigg East and West (Round 1 sites) being nominally in Scotland but connected via the English coast.

Hull has been successful in attracting the only wind turbine generator construction facility in the UK, along with blade manufacture.

At a national level, the support has been considered to be less clear. The changes in governing party have been a part of this as each change (Labour to Conservative / Liberal Democrat coalition, Coalition to Conservative majority) was seen as being less supportive of renewable energy. More concrete signals which reduced participants' confidence in support were the energy market review (seen as a cost control exercise by many offshore wind conference delegates), the dissolution of the Department for Energy and Climate Change with its responsibilities being rolled into the new Department for Business, Enterprise and Industrial Strategy and the renewed government promotion of nuclear power. The actual outcomes of the changes have impacted other renewables technologies more than offshore wind (neither solar photovoltaic power nor onshore wind power are eligible for the Contracts for Difference support mechanism) and the industry has demonstrated a resilience to the reducing levels of support – as one interviewee said of the EMR:

> *'In the end as long it creates a funding system that lets people make a return then you can live with it.'*

It is argued above that the change-over to CfD negatively impacted the emergence of the industry (via delay) and it is reasonable to consider reduced confidence in central government support also contributed to this. Equally one can see the impact on viability has been to focus on removing the impact of government funding by getting to a subsidy free future:

> *'The industry will cease to need subsidy* [by the middle of the next decade]*, certainly no more than fossil fuels.'*

A fourth facet of external support for the industry has been the development of legislation that recognises the changing business context due to the arrival of offshore wind power generation. There have been a number of pieces of legislation that enact the changes to the market support structure, and there is the Climate Change Act that made government action on the reduction in fossil fuel use a binding commitment. These have been discussed in earlier sections in the context of the actions the legislation enacts. A final piece of legislation is the Marine (Scotland) Act 2010. This legislation was enacted for Scotland to '*help balance competing demands on Scotland's seas. It introduces a duty to protect and enhance the marine environment and includes measures to help boost economic investment and growth in areas such as marine renewables'* [https://www2.gov.scot/Topics/marine/seamanagement/marineact accessed 20/2/19]

The main measures included specific elements around marine licensing with the intent to provide '*a simpler licensing system, minimising the number of licences required for development in the marine environment to cut bureaucracy and encourage economic investment'*.

This is widely seen by the interviewees to have been a failure – although as one interviewee put it '*people are judging the process by the outcome they get rather than the process itself'*. The impact on the emergence of OWP in Scotland has been clearly negative. This is both in terms of delay (costly in itself), and in because the delay slipped projects from the ROC regime to the CfD regime which is less supportive financially and so reduces the return from projects.

The learning for legislators interested in supporting industry during an emergence phase is perhaps that change during this phase is inherently risky. There should be significant benefits that are being actively sought by stakeholders (rather than just desirable).

Overall, while the change in marine planning in Scotland has damaged the emergence of the industry it has not reduced its viability and may be considered to have enhanced its viability through the successful defence of a legal challenge.

The final facet of the external support to offshore wind power has been the funded innovation programmes. BVG Associates, a renewables energy consultancy, produced a list of funds that could support innovation in renewables. 47 funds were identified that directly applied to offshore wind, 36 of them from the UK (BVG Associates, accessed 6th August 2019). There is clearly a lot of scope to apply for funds as an individual organisation.

The most visible innovation programmes from the offshore wind conference are the Offshore Wind Programmes Board (following on from the Cost Reduction Task Force report) managed by the Offshore Renewable energy catapult and the Offshore Wind Accelerator (OWA) managed by the Carbon Trust. This is supported by government (via the Scottish Government) and is an industry led programme (see Carbon Trust, accessed 7th August 2019).

The Offshore Wind Programmes Board remit was to *'treat the UK's offshore wind sector as one business by assessing risks and barriers and tackle these by helping to find and implement solutions in partnership with the wider industry'*. The Offshore Wind Accelerator aims to *'to reduce the cost of offshore wind to be competitive with conventional energy generation, as well as provide insights regarding industry standard (and best practice) health and safety requirements'*.

It has been shown that the innovation activity in the industry has been highly successful in its focussed task of reducing the levelised cost of energy (LCoE). It is also clear there has been a great deal of activity in innovation support from external bodies – government and others. The participant's view is the primary drivers of LCoE reduction have been in the increasing scale of turbines and the reducing risk premium from investors. This is important as the innovation programmes discussed do not directly address these areas e.g. the OWA areas are listed as Access

Systems, Wake Effects and Wind Resource, Offshore Foundations, Electrical Systems, Cable Installation.

This is not to say the innovation programmes have not had a part to play but to demonstrate that the innovation support element is more nuanced than the success in cost reduction suggests.

From the standpoint of its impact on industry emergence and on the industry's viability, innovation support has been positive even though one interviewee felt the outcomes would have been the same without the support. The deciding factor in this is that even accepting the cost reductions came from other mechanisms (e.g. competitive pressure on turbine manufacturers), the high level of collaboration and inter-organisation communication on innovation has benefited the cohesion of the industry. An anecdotal demonstration of this is the perceived negative impact on innovation (through reduced collaboration) when the CfD mechanism became active.

The following table (table 4.42) attempts to display the overall impact of the external actions on the offshore wind power generation industry. Red indicates a broadly negative impact, green a broadly positive one. This assessment is purely qualitative and attempts to recognise that one negative impact can outweigh all the positive impacts and vice versa.

Table 4.42: External impacts on the emergence and viability of Offshore Wind Generation as an industry.

Facet	**Action**	**Impact on Emergence**	**Impact on Viability**
Crown estates role	Offering sites for lease		
	Development Rounds		
Energy market reform	Establish ROC for 'renewables' (not nuclear)		
	Setting preferential ROC		
	Change to CfD		
	CfD auctions		
	Removal of Onshore & Solar from CfD		
Policy	National Govt		
	Regional (Scottish)		
	Local (Hull)		
Related legislation	Marine Planning		
Funded innovation programmes	Cost reduction task force		

The primary contribution of this table is it shows that programmes that support the emergence of an industry do not automatically improve its future viability. It is equally true that actions which have a short term detrimental effect on the industry do not necessarily damage it in the longer term, and may instead strengthen the industry in the longer term by the development of ‘problem-solving’ capability.

4.7 How this case answers the research questions

This section will review how the case study has been able to answer the research questions set out in Chapter 3 before leading on to Chapter 5 which will consider the implications of the case findings for the knowledge base on new industry emergence.

4.7.1 RQ1 Does OWP follow the pattern of emergence identified in the literature?

The literature review identified the lack of research studies that investigated an industry during its emergence stage. This provided the underlying impetus for the research - the need for understanding the drivers and indicators for emergence within a complex product system industry.

The goal to consider the range of drivers for emergence and to understand how they may interact with each other required a broad observation of the activities of the industry. The mixing of observation of industry events, the collation of data on projects and the interviews with key actors in the industry has built a rich case study of the industry which allows role of the previously identified drivers to be investigated and illustrated. These observations point to a broad congruence between this industries behaviour and the drivers (discussed in more detail in the next chapter).

Similarly the observations allow the indicators of emergence to be compared to existing literature. There is more divergence between the observed behaviour and that described in the literature. Particular indicators of emergence did not apply within this industry and others were seen to be less relevant. The extent to which these observations suggest a divergence between complex product system industries and mass manufacture ones, rather than being specific to this case is discussed more fully in the next chapter.

The case detail is considered to be sufficiently comprehensive that any other drivers for the emergence of the industry that existed would have been apparent. Whilst the case has some specifics that were highly important for the offshore wind power industry (e.g. a single owner of the sea bed), no other generalizable drivers were identified.

4.7.2 RQ2 What can be learned from the observation of an industry during its emergence?

The use of the ‘systems lens’ has provided a mechanism for the identification of the industry (see Section 4.2 in this chapter) that is independent of the observer and allows for the blurred boundaries of the industry that SIC code and firm selection approaches do not. This structure then provides a framework for the discussion of the target case’s independent identity as an industry (see section 4.6.1 above).

The consideration of the case industry ‘as a system’ has also supported a contemporary understanding of emergence that is independent of the pre-existing indicators of emergence (e.g. accelerating growth, firm fallout, rise of a dominant design). This is important as the pre-existing indicators may not be apparent until later and may not be as relevant for a particular industry (as shown above). Emergence is shown as an interaction of multiple factors that can be assessed at multiple levels – the industry’s place in the wider economic system, the industry system as a whole and the individual sub-systems of the industry. The state of emergence can then be discussed and assessed (see Section 4.6.2).

The consideration of viability (the ability for an industry to continue in the long term) has not been a feature in existing research into emerging industries. This is likely due to the researches focus on industries which have emerged and continued to the point of study. This research is able to consider ways in which ‘viability’ can be conceptualised (ability to identify and address challenges to the industry as a whole) and assessed (building upon systems thinking frameworks – see sections 4.6.3 and 4.6.4). This approach gives new insight into the separate outcomes of emergence and viability – i.e. successful emergence does not necessarily lead to on going viability – that adds new dimensions to be considered when interacting with emerging industry.

A final aspect of observing an industry during its emergence is that the drivers identified in pre-existing literature are seen to behave more as cause-effect loops. An example of this is legitimacy a driver for emergence. In the pre-existing literature it is shown that activities supporting legitimacy of the industry supported its emergence. In the current case it can be seen that successes towards emergence (e.g. first planning submission approved, first power etc.) also give legitimacy to the industry. While this is not a contradiction of the literature (discussed more in the next chapter) it does indicate that a fuller understanding is required if one is to take appropriate action in support of an emerging industry.

The case does show that actors (within the industry and interacting with it) can take actions that positively impact on both the emergence and viability of an nascent industry. Whilst the case does not surface structures and processes to guide these actions, the analysis does suggest that such a framework may be constructed by bringing together insights from a systems perspective and tools to support the contemporaneous assessment of both emergence and viability.

Chapter 6 sets out a proposed framework and shows how it can be initially tested with reference to a separate but related industry.

5. Discussion

This chapter will discuss the findings of the research to identify what knowledge is being contributed by the work. This will be covered in two sections – the first considers the case findings as they relate to existing literature while the second considers the insights gained from observing the industry through a systems lens while it emerges.

New contributions to the knowledge are highlighted in boxes as follows:

> Lorem ipsum dolor sit amet, consectetur adipiscing elit. Pellentesque imperdiet ultricies magna eu interdum. Duis ac urna nec sem pulvinar viverra in sit amet lectus. Etiam id ullamcorper urna.

The final section discusses the generalizability of the findings.

5.1 What does current literature have to say about the findings

It is important to state from the beginning that this research has addressed a limitation inherent in all the reviewed papers and identified explicitly by Tanner (2014) that investigations of emerging industries are after the event. Tanner states that:

> *"Owing to the inherent temporal focus of both approaches* [clusters and industry life-cycle studies] *to industry development after market introduction, cluster- studies and industry life cycle-studies face difficulties in grasping the essentials of how new industries come into being"*

This study has observed an industry during the emergence period and has been able to contribute to the knowledge base on emerging industry as a result.

> The documenting of an industry during its emergence is a new contribution to the knowledge base.

This initial discussion of the results therefore covers the ways in which the case supports, extends or contradicts the existing literature. The review of existing literature identified drivers and indicators for an emerging industry. The table is reproduced here.

Table 5.1: Drivers and Indicators for emerging industry.

Drivers	Indicators of emergence
Technological discontinuity Market discontinuity Entrepreneurial action Legitimacy Institutional isomorphism Risk reduction – through policy Risk reduction – through technological support ‘Local’ technological antecedents	Dominant designs Accelerated sales growth Firm shake-out Move from product to process innovation

Discontinuity

It is arguable whether there was any technological discontinuity leading to the emergence of offshore wind power (early offshore wind turbines were little different to onshore), however there was a significant discontinuity when leases for seabed areas to be used for offshore wind power generation became available. This is not exactly the same as a market discontinuity within power generation (e.g. de-regulation of stock trading); the financial support mechanisms for non-fossil fuel power generation have been open to a number of technologies and the market building actions that reinforce offshore wind’s position (additional ROCs, removal of onshore wind from CfD auctions) occurred in parallel with the technology’s deployment.

As Peltoniemi (2011) noted, exiting studies and theory development have focussed on mass manufacture technologies rather than complex product systems. In this case of a complex product system industry, the branching is directly related to a ‘discontinuity’ (the leasing of the seabed for the specific purpose of wind generation projects). It is possible that even with this discontinuity, the industry may not have emerged i.e. other factors such as policy support, subsidy, technology are also important.

This finding suggests that any discontinuity in the product – market – regulatory regime that can give an impetus to the ‘branching’ of a new industry.

Entrepreneurship

Entrepreneurship is seen as a prime mover in industry emergence (see Aldritch and Fiol 1994, Feldmann 2001, Izushi and Aoyama 2006, Vasi 2009 and Peltoniemi 2011 for examples). The importance of the individual is further underscored in Klitkou and Godoe (2013) in which the authors identify that 'technological agency' (purposive technological action and decisions) can counteract market-based approaches which might make an industry unfavourable.

Both aspects have been apparent in the story of offshore wind's emergence. Early developers such as Mainstream and SeaEnergy were led by entrepreneurs – some who continued with the organisations and some who sold firms on and started other developments. Equally there were individuals who left other industries to be part of the emergent industry – some as entrepreneurs, and others who joined existing firms to make things happen; *purposive technological action and decisions* in Klitkou and Godoe's words (Klitkou and Godoe 2013).

One interviewee ('F') observed that;

> *"It is actually quite a small number of people (circa 10) who went to do this. The government didn't see it coming."*

This finding confirms the existing knowledge of the role of entrepreneurship in new industries and shows it can apply in a complex product system industry.

Diversification

Diversification is described as an additional source (e.g. Tanner 2014, 2016) of industry branching. This can be seen in the involvement of utility developers in the industry. One of the interviewees ('F') suggested that early involvement in leasing rounds was driven by a concern of being excluded (*'people scrambled to get sites so they wouldn't loose out'*) rather than by a vision of a successful future industry. This may have been exacerbated by the bid and award rounds of the leasing process forcing a deadline for corporate decision making.

The experience of observing the emergence of an industry gives a strong impression of the importance of individuals. The offshore wind conference had a core of panel members, active in the industry, who were highly visible year on year (e.g. Ronnie Bronner, Allan MacAskill, Benj Sykes) and could be seen to be progressing the industry, moving between antecedent industries (e.g. oil & gas), developer organisations and supporting institutions.

Legitimacy

This leads on to another aspect that existing literature highlights as important – the development of legitimacy in an industry. Feldmann (2001) shows how entrepreneurial action leads the development of a supportive environment for entrepreneurship. The author identifies the development of supportive social capital as one of the aspects of entrepreneurship – this is mirrored in more detailed entrepreneurship literature (see Westlund and Bolton 2003, De Carolis and Saparito 2006, Cope et al 2007 and Martin et al 2013). Social Capital is taken as Bourdieu's definition (Bourdieu 1980 quoted in Westlund and Bolton 2003);

> *"the sum of the resources, actual or virtual, that accrue to an individual or a group by virtue of possessing a durable network of more or less institutionalized relationships of mutual acquaintance and recognition"*

The early legitimacy of the industry was supported by government policy action (e.g. ROC's, Climate Change Act goals) and the The Crown Estate's concrete action in letting leases. The 'empty category' fate (see Edman and Ahmadjian 2017) was arguably avoided by the building of a distinct identity for offshore wind power via the network of utilities, developers and marine engineering companies who started investigating and discussing the opportunity through events such as the offshore wind conference.

Maintaining, or indeed building, this legitimacy has been one of the most visible aspects of the annual wind power conference. This has been done through the attendance of high profile political figures (either the First Minister of Scotland, or the Minister for Business, Innovation and Energy attended every conference during the study), the consistent addressing of the central challenge (cost reduction – plenary session in 4 of the conferences) and sharing experiences that showed projects can come to fruition (a project round-up was a feature of each conference). In this, the findings mirror the work of Dodd et al (2018) who found that public expressions of optimism were often in advance of privately held views.

It should be noted that building legitimacy was not an inevitable outcome for offshore wind power. Early private discussions held by this author with engineering leaders in Scotland frequently showed a high degree of antagonism towards all aspects of wind power (onshore and off). This scepticism was captured by interviewee 'F' who said:

> "[People thought] *'it'll never happen, it's too expensive, too complex, we're not going to need it, lots of space onshore'; and it HAS happened.* [They then said] *'If it does happen it'll be in the southern North Sea, not in Scotland'; but there is significant investment in Scotland (Beatrice, MORL, so far...)."*

The findings around legitimacy as a driver for industry emergence are congruent with existing literature, but suggest that the interaction in a specific industry is more complex. The observed behaviour in the Offshore Wind Power industry is that there is a feedback effect (causal loop) where legitimacy supports growth and successful growth boosts legitimacy. This aspect would benefit from future investigation in studies of industry emergence.

Institutional Isomorphism

Institutional isomorphism in this research context describes the drivers that shape organisations. The broad forms are memetic (the pressure to take existing organisational forms); normative (the pressure to take prescriptive forms); coercive (the pressure to be like others). This is discussed in Mezias and Schloderer (2016).

Some of these pressures were observed within the offshore wind industry in the process of emergence. As an example there was a lot of audience discussion over the two forms on developer organisation (independent – Mainstream and SeaEnergy or utility based – SPR, SSE). Received wisdom being that a developer needed to be hosted within an utility to afford the development costs (normative pressure) despite both forms successfully bringing projects to conclusion.

There were also coercive pressures on the contract forms in early stages. The wind power conference being aimed at the supply chain, there was a lot of discussion about who would be bidding, and for what. The experience participants had of other industries before starting in offshore wind pushed towards relatively large packages of work going to prime contractors who would then engage smaller sub-contractors. This was discussed in plenary sessions of the early OWP supply-chain conference (see 2011 – 2013 for examples).

Given the small number of organisations involved in the industry (normal for CoPS industries but unusual in mass manufacture industries), the memetic institutional pressures are modified by inter-personal relationships and direct knowledge of firms' situations. So when, for example, SeaEnergy (an independent developer) was sold to Repsol (a large energy company), the reaction was not that it demonstrated the need to be a large company to afford development, but that it was a good way for the entrepreneurial directors to 'cash in' from their efforts to date.

The literature on the expected role of isomorphism is broadly supported in this work. The understanding is extended for a complex product system industry by finding that organisational forms are less important (due to the smaller number of organisations compared to mass manufacture industry) than other institutional elements e.g. contract forms.

Risk reduction - technology

Risk reduction is identified in the literature as a key aspect of supporting the emergence of new industries – both through reducing technical risk and through policy support.

The case identifies the innovation sub-system success in reducing the levelised cost of energy (LCoE). This success was partly through reducing the risk premium on finance for the projects.

The industry carried out a number of demonstration projects e.g. Beatrice where 2 x 5MW turbines (the largest deployed at the time) were installed in deep water (over 40 m) using jacket structures for the first time in 2007. It is arguable that such projects were more to reduce perceived risk than to develop technology.

It was also the case that a number of other developments were planned to trial and demonstrate technologies but which did not come to fruition in the intended timescale to support the later Rounds' development plans. The European Offshore Wind Deployment Centre (EOWDC) in Aberdeen bay is a particular example. It gained initial consent in 2013 and was intended to give operational data for the planned large scale Round 3 sites. Ongoing planning challenges meant that construction did not start until October 2016 (see Vattenfall, accessed 7th August 2019), with first power in 2018 only just ahead of the first Round 3 sites.

It is arguable that the industry's joint research and development activities have been focussed on demonstrating the feasibility of technologies to reduce technical risk (e.g. use of foundation technologies from oil and gas, not previously used in offshore wind), rather than to trial out completely new technologies. However it is clear that technical risk reduction action has been a part of Offshore Wind Power's emergence as an industry.

This work confirms previous case literature findings on the role of technical risk reduction for emerging industries.

Risk reduction - policy

The picture for policy-based risk reduction for the industry is less clear. The work of Carlos et al (2018) highlights the capability for policy to reduce the general risk burden for entrepreneurs e.g. by increasing legitimacy. This straight forward view is contrasted by the work of Matti et al (2017) who point out that individual firms feel the impact of all the levels of policy instruments at the same time and so a multi-level understanding of the policy mix is required.

In this case, the impact of that multi-level policy activity can be seen. At a regional level there has been consistently high levels of policy support for offshore wind, particularly within Scotland . This has usually been entirely positive (e.g. support for demonstrator sites) with some 'good intention' policies not working out (Marine Scotland). At a national level the impact of policy movement has been to introduce uncertainty. While this is not the same as increasing specific risk, it does increase the perceived risk for involved organisations.

Later sections will discuss the impact of policy and risk on the emergence of the industry. At this stage it can be seen that this case confirms the findings of previous case literature on the matter while suggesting a more complex impact on the viability of such industries.

Technological Antecedents

The final driver for industry emergence identified in the literature (as ordered in the table 5.1 above) is the availability of technological antecedents for the new industry in the local area the industry is emerging. Tanner (2014) sets out the orthodox forms of this understanding and in her own work shows that other contextual elements can overcome the lack of appropriate technological antecedents.

The case of offshore wind power is arguably simpler than that. There are clear technological antecedents for the industry in both the oil and gas sector (for construction operations in offshore waters) and in wind power generation from onshore experience. A number of the interviewees came originally from one of these two industries.

There are interesting perspectives that come from direct discussion with the 'technological antecedents'. To quote one of the oil and gas entrées (interviewee 'D');

> *"I came in as an arrogant oil man, this is very easy. It is actually a technically advanced industry – but in a different way to oil. It is not bespoke tech* [as oil developments tend to be] *it is serialised technology (although not mass-manufacture)."*

Similarly from one of the interviewees (interviewee 'C') coming from a utilities background;

> *"Prior to privatisation the* [electricity generation] *industry used to spend a lot on R&D – this stopped 'overnight'. Since then there was 20 years of 'we just buy mature products'. This gave a cultural barrier* [for offshore wind] *innovation = risk = more cost.*
>
> [supporting institution] *is saying actually innovation is about taking risks out, its about doing things better – learning things, get what works take cost out of the next project. Its not about INVENTION of new products, it's innovation."*

While these interviewees were clearly bringing a belief in the underlying technology from their experience in the antecedent industries, they also considered that they were having to work *against* the norms from these antecedent industries.

While this work confirms previous case literature findings that antecedent industries impact emerging industries it adds the insight that there is a potential for this impact to be negative. In the case of OWP antecedent industries are resistant to being first users of a technology.

Dominant Design

As well as identifying drivers for industry emergence, the existing literature establishes a number of indicators of industry emergence. The first of these is the establishment of a ‘dominant design’ from a field of diverse product offerings. The ‘dominant design’ is not necessarily the most technically proficient design but the one that gains enough traction that alternatives are not pursued further. The classic example is between VHS and Betamax standards in home video recording.

This indicator is problematic for offshore wind in that no alternative configurations of design were considered. The de-facto standard of 3-bladed, upwind turbines on single column masts has been used for all commercial scale projects. As interviewee ‘B’ put it, early designs were an ‘*onshore turbine with a life-jacket on it’*.

It is worth considering whether this is an impact of the industry being a CoPS industry rather than a mass manufacture industry.

In a CoPS industry, the controlling interest is with the system-integrators (see Rutten et al 2009). They aim to provide combined technical solutions that meet the needs of their customers. In capital intensive projects, both construction risk (potential for unforeseen issues delaying, or increasing the cost of, construction) and life-operation risk (potential for reliability issues or operational limitation reducing operating time) have a significant impact on technical choices with known capability having greater weight than unproven advantage. In this case the availability of onshore turbine technology offered a low level of risk for long-life projects and a relatively straight-forward development path to future larger turbines (bigger blades, larger generators, taller masts). As identified above, there was a cultural bias amongst the utility organisations to stick with mature products which would also count against more radical technologies. Interviewee ‘D’ talks about *‘innovation has to be possible stepwise’*.

In this case it is clear that the ‘good enough’ technology was not going to be challenged during the establishment / emergence stage. It is not possible to determine if this is a norm for CoPS industries from this single example however the logic of risk-minimising approaches by the selectors of technologies for long term projects is compelling.

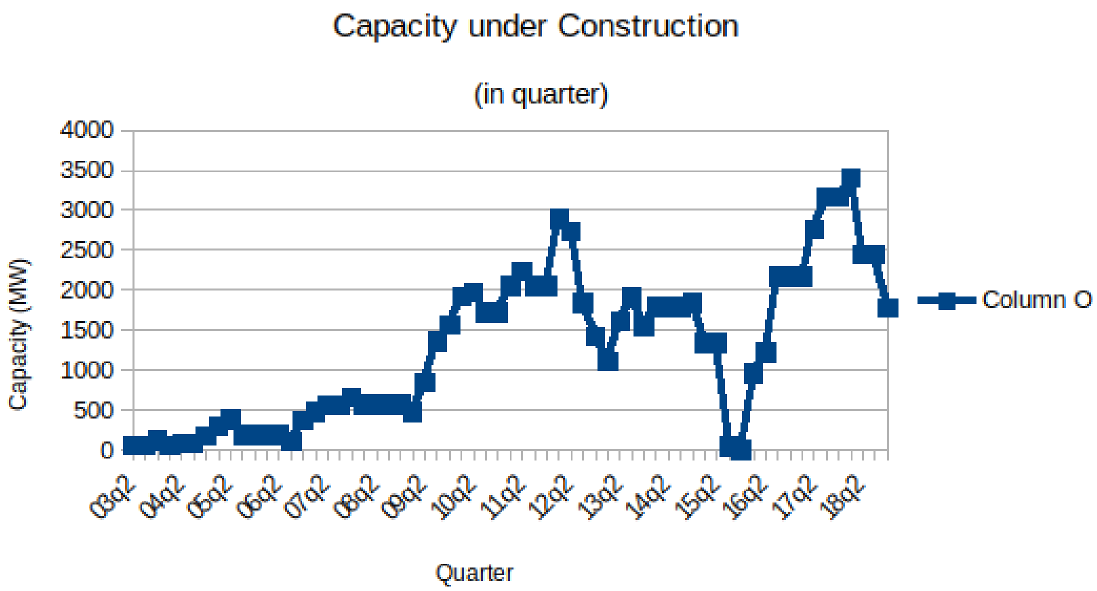
This finding provides new knowledge on the role of dominant design in a complex product system industry. This does not necessarily contradict previous knowledge but shows that the role of dominant design is different in CoPS industry.

Accelerating Sales

Another indicator for an emerging industry is the acceleration of sales showing the establishment of a growing sales trajectory. In this case the raw measure is heavily impacted by two constraining factors initially (availability of suitable sites for development and the securing of planning consents) followed by a third constraint when the industry moved from Renewables Obligation certificate as a support mechanism to Contracts for Difference (securing of a Contract for Difference).

Again the particular circumstances of this CoPS industry can be considered to be modifying the ‘regularities’ seen in existing literature. If the sales measure is considered as the capacity under-construction in a given period then some step growth can be seen (see figure 5.1 below). Direct measures of sales (e.g. MWh generated in a period) are constrained by the capacity installed and boosted by policies on procuring energy and so the capacity constructed is considered the most appropriate measure.

Figure 5.1: Capacity under-construction in each quarter 2003 - 2018



(Source UKWED)

The signalled intention by the UK government to let Contracts for Difference for a given capacity level for the next decade will continue to place an upper bound on the projects reaching final investment decision, and hence moving to construction. It may be seen as a measure of the industry moving to its next stage (stable growth) that the CfD constraint on growth is removed due to projects becoming subsidy free. Although it should be noted the government will still have ultimate control over what capacity is constructed via the PINS consenting mechanism.

This case does show some of the features of accelerating growth as a measure of industry emergence, however this signal is heavily impacted by the influence of a single stakeholder (Government). The case calls into question the utility of the growth measure as an emergence indicator for CoPS industries. Different, but analogous, measures may be more appropriate.

Firm entry & exit rates

Much of the work looking at product/technology industry emergence makes use of firm entry (initially) and firm shake-out (as emergence stage ends) as important indicators of where the industry is in its life cycle. While the industry has seen firm entry and exit in absolute terms the number of firms involved is small.

The findings section above makes the case for the developers being the core of the industry. This conforms to the treatment of systems-integrators in e.g. the work of Hobday and Acha (see Hobday 1998, Acha 2004). Independent developers (SeaEnergy, Mainstream etc.) were highly active in the early industry, and utility developers now play a more dominant position (Oersted, SSE, SPR) however this picture obscures the fact that the independent developers (and/or their projects) were acquired by larger organisations and so they haven't actually left the industry. Also the larger utility developers have started out in the industry, left the industry and then returned (e.g. EdF). This suggests that firm entry and exit rates are not a useful indicator of CoPS industry emergence.

It may be that the problematic indicators of firm entry and sales growth are better addressed by combination when considering a CoPS industry. The firm entry indicator might be supplanted by the number of projects being initiated and the sales growth indicator by the number of projects achieving a final investment decision (FID).

> The finding on firm entry and exit rates is contrary to existing literature for mass manufacture industries. This may be a feature of the smaller number of firms involved in this complex product system industry. It provides an extension to the existing knowledge base by reducing the relevance of this indicator for emerging new CoPS industries and suggesting an analogous alternative.

Innovation Focus

The last indicator of industry emergence identified in the literature is that the focus of innovation moves from innovation in product to innovation in process. This is also sometimes seen as a change from radical innovation to incremental innovation.

Innovation is seen by the interviewees as a significant success for offshore wind. The key metric of achieving a LCoE below £100/MWh is widely used as the indicator of this success. It is arguable that this success has been achieved through incremental innovation rather than the radical innovation expected during the emergence stage of an industry. The consistency of the dominant design in turbines is an example of this (at the time of writing all installed offshore wind turbines are fixed foundation, tower mounted, upwind rotor, 3 bladed wind turbines).

A specific element that can serve as an exemplar is the transmission technology. Gearboxes are used to multiply the blade speed to allow it to drive the generator at the speeds it requires. Gearboxes are the source of most maintenance requirements in wind generators (number of bearings, moving parts, need for oil changes etc.). An obvious improvement is to redesign the generator to remove the need for a gearbox. There were early designs of such 'direct-drive' wind generators, but they were more expensive than traditional forms. After a number of generations of growing turbines, and including hybrid designs (reduced gearbox stages), direct drive turbines are only now coming to market.

Interviewee 'C' identified the incremental innovation path as being important for the success of the industry:

> *'If you look at barriers to getting full potential – it wasn't the technology. Issues were about scale and delay around the processes that put the projects together. You could see this was eminently doable – nothing had to be really invented to get cost down.'*

In this case the observer must question whether radical innovation had a role in the emergence of the offshore wind industry. Indeed, one of the potential ways forward for offshore wind power is to bring in *more* radical innovation now it has established its credibility. This suggests a key difference between CoPS type industries and the more researched product-based, mass-manufacture industries.

> The finding on the nature of innovation is contrary to existing literature for mass manufacture industries. Further research with other complex product industries is required to identify whether this a feature only of offshore wind power.

5.2 What can be learned from observing the industry during its emergence?

The above section shows that the current case is broadly consistent with the established literature on industry emergence. There are contradictory elements such as dominant design, firm entry/ exit rates, innovation nature. These are considered to be driven by the nature of a CoPS industry – an under researched aspect of current theories – and represent new knowledge of this phenomenon.

As has been highlighted, this study of the emergence of offshore wind power is the first study of an industry to take place during its emergence – what insights are gained from this experience? The literature review establishes Systems Thinking as an appropriate lens through which to observe industry behaviour as a whole entity.

The following sub-sections discuss:

- Understanding the structure of the industry
- Systems interactions within the emerging industry
- Ways of engaging with the industry
- Behaviour of the industry as a system progressing to self-sustainability

5.2.1 Understanding the structure of the industry

It is proposed in the literature review that using a systems definition of an industry can help address the completeness concern of working with SIC codes while also avoiding an excess observer bias through the process of selection on the industry boundaries.

The rational for using a systems definition of an industry is that a generalised concept of industry meets the system definition requirements (summarised from von Bertanlanffy 1973, Checkland 1999)

- An industry (system) is a series of interconnected entities (organisations) and processes (making, buying, selling, transporting)
- The whole behaviour of the industry (growth, innovation, decline) is not predictable from the behaviour of individual nodes (firms)
- The boundaries are not fixed, the point at which interchange between nodes within the system and the general environment occurs can move; nodes within the system can exit and vice versa

As Checkland makes clear (Checkland 1999, pp7) the goal of Systems Thinking is to move beyond the theoretical formalism of General Systems Theory to tackle ‘real’ problems. The discussion of industry-as-a-system needs therefore to be more than a matching of characteristics between a theoretic construct and an observable example. There must be utility in this formalism. Considering the systems concept of hierarchy shows how this formalism can help with the definitional difficulties of industries as a unit of analysis.

Hierarchy is a recurrent theme in systems – both in terms of classes of systems (Boulding) and in the structure of systems of a particular type e.g. organisations in VSM and LST. Considering the industry in focus with a hierarchy can help the investigator in the following ways;

- to locate the boundaries in terms of the wider environment (level above)
- to highlight the defining ‘sub-systems’ of the industry (level below)
- to show how system purpose is maintained (within the hierarchy)

In setting a ‘level above’ context for an industry, the investigator allows for the blurring of boundaries by setting the environment which the boundaries will merge into. In the context of Offshore Wind Power, there are a number of higher level systems which may be considered as setting this environment;

- National / Regional Innovation System
- Electricity Generation Market
- Marine Engineering
- Renewables Power Generation
- National economy
- Regional Economy

By recognising these broader systems, the investigator can make defensible, rational decisions on;

a) what is included in the industry in question,

b) what directly influences the system but is external and,

c) what is external and does not directly influence the industry.

Crucially, for considering the industry as a single unit of analysis, organisations are able to be identified as ‘in’ the industry, ‘mostly in’ the industry, ‘somewhat in’ the industry and ‘not in’ the industry thereby defining the internal and external limits of the blurry boundaries. The definition of the industry is unchanged when a new company enters one of the pre-defined levels e.g. a spin-off from a utility becomes a developer, or when a firm leaves. Section 4.2 sets out this tiered description of industry membership.

When considering the ‘level below’ perspective of an industry there are many possible choices of sub-systems. They could be the individual supply chains coalesced around individual developers, they could be the collected activities across projects (e.g. environmental impact surveying, front end engineering design, Wind Turbine Generator manufacture etc.) or some broader characteristic of the industry.

The division into sub-systems that was finally selected arose from observation of the Offshore wind Power conference presentations and plenary sessions. That the sub-systems identification should be emergent from the observations helps mitigate concerns of observer bias and demonstrates a grounded-ness to the research. There is, however, an element of prior identification in this selection. One of the VSM requirements is that each of the subsystems should also be viable systems. This is considered as a helpful guide in the selection of sub-systems rather than a formal restriction but does impact on the final selection. (In practice – Can the investigator envisage that the sub-systems could be considered as viable systems in their own right?).

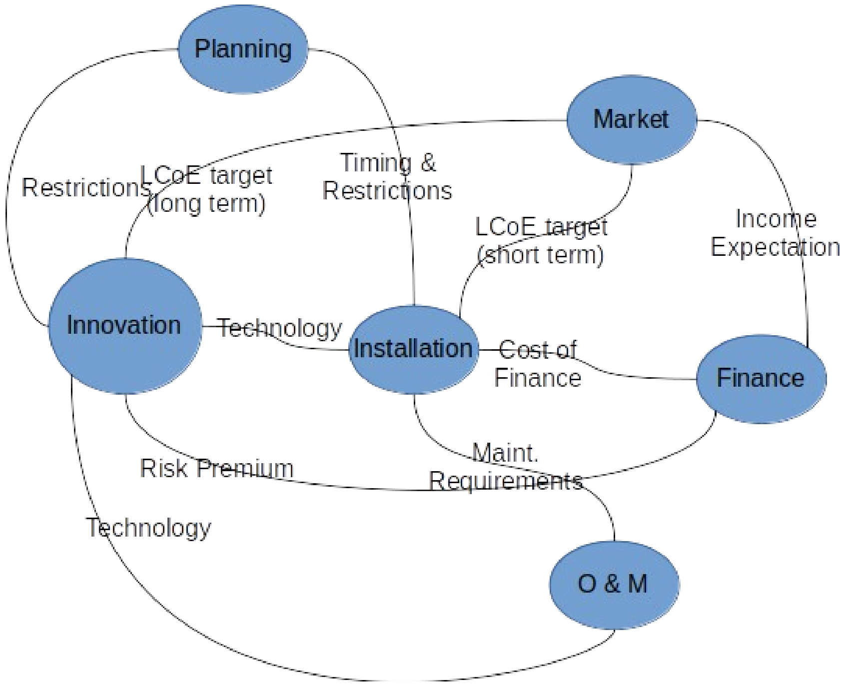
The sub-systems so identified were as follows:

- **Planning**: This sub-system relates to all the activities undertaken to get proposed project consented. One of the proposed benefits of offshore wind over onshore is the ability to gain planning permission for large scale projects.
- **Market Regulation**: This sub-system sets out the ‘rules of the game’. Electricity generation is a ‘de-regulated’ industry but in comparison to product-based / mass manufacture industries there are significant legal structures. Core to this sub-system are the leasing rounds, the subsidy regime and the transmission rules (the need for an OPTO to connect each project). Some affect planning and (PINS and Section 36) are considered in that sub-system.
- I**nnovation**: This sub-system encompasses the activities undertaken to enhance the design of offshore wind farms. The activity is more focussed on installation elements (wind turbine generator, foundations, sub-structures etc.) but does encompass operations and maintenance elements (condition monitoring, access systems etc.). Unlike the previous 2 sub-systems it is largely unconstrained by legislation or other legal frameworks.

- **Finance**: Financing is the sub-system that relates to all the aspects of procuring funds for a given development. The research observation started at the point when it was becoming clear that the financial-based recession was following an abnormally protracted recovery track. The procurement of finance was a significant concern, and perhaps had excess prominence in the early conferences. The nature of capital outlay of the projects (i.e. all expenditure before revenue generation) makes the cost of energy highly sensitive to risk premiums on finance – underpinning the importance of finance as an industry sub-system
- **Installation**: This is the most visible sub-system for the industry and covers all the activities of the project leading up to final commissioning. This sub-system can be seen to encompass all the project stages that would have been in included in a project based decomposition of the industry.
- **Operations & Maintenance**: The final sub-system identified is the operations and maintenance activity of the industry. During the majority of this research programme the O&M aspect has played a minor role and is less prominent as a result. Nonetheless it is equally important as installation to the industry going forward, and for the regional economies on the near shores from offshore wind farms it is more important.

As these sub-systems become clear it is possible to determine the nature of the interactions between them. Figure 5.2 below seeks to highlight the principal interactions between the sub-systems. This is further explored in table 5.2 (below) which sets out the nature of these interactions.

Figure 5.2: Model of the industry Sub-systems



The schema shows that there is a significant scope for emergent behaviour from the complexity of the interactions. This helps validate the model structure. The actual linkages are described in very simple terms and are in fact more complex, and to an extent bi-directional.

The following table (table 5.2) shows how these linkages might be described in more detail.

Table 5.2: Influences between industry sub-systems

	Influence By					
Influence on	Planning	Market	Finance	Innovation	Installation	O&M
Planning		Nil	Nil	New technology impact	Nil	Nil
Market	Nil		Nil	Expected LCoE	Annual budget	Annual budget
Finance	Projected project timescale	Projected returns		Projected returns	Capital requirements, returns	Projected returns
Innovation	Blade heights, noise etc	Long term LCoE goal	Capital v operating costs		Project challenges	Project challenges
Installation	Methods, reporting, timescale	Project design, Short term LCoE	Project phasing (FID)	Methods, technology		Operating experience
O&M	Operating restrictions		Annual budget	Methods, technology	Maintenance requirements	

The systems lens thus makes it possible to describe the industry objectively without the observer selecting firms that are included or excluded. The final element of describing systems, is that a system has a purpose – identified by the mnemonic POSIWID (the Purpose Of a System Is What It Does). The purpose of Offshore Wind Power is to generate electricity offshore, where the visual impact is negligible and the wind resource is ‘better’ (more stable winds and stronger winds).

This purpose observed in the sub-systems (POSIWID) is as follows.

Table 5.3: Sub-systems and purpose

Sub System	**Purpose**
Planning	Fast approval of robust (wind farm) proposals
Market	Affordable support of non-carbon generating technologies
Finance	Access to necessary capital for infrastructure projects
Innovation	Cost reducing technologies for wind generation of electricity offshore
Installation	Development and installation of offshore wind farms
Operations & Maintenance	Maximising the operating time and efficiency of offshore wind farms

The above table can be certainly be critiqued, both in terms of the primary focus of each sub-system, and in terms of the level of awareness that participants have of such a purpose. However the main consideration in this argument is that the sub-systems described can be thought to have distinct and semi-independent purposes that add together to describe the overall industry goal.

This section shows how seeking to observe an industry within the formalism of a system can overcome the boundary issue by focussing on the activities within the industry rather than any specific company or group of organisations. Thus the industry as an entity is decoupled from sets of companies and organisations.

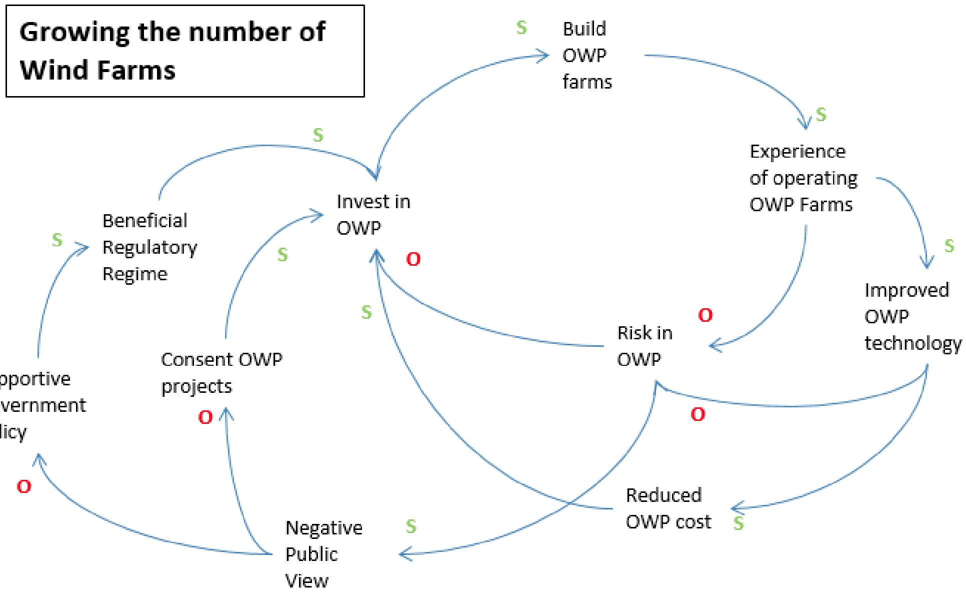
5.2.2 Understanding system interactions in the industry

The literature review investigates a number of systems approaches that can be used to understand the interactions between elements of the system in focus.

In the Fifth Discipline (Senge et al, 1994), the technique of causal mapping (see Sherwood 2002 for a full explanation of construction) of system elements is used to set out particular regular patterns of interaction (system archetypes) whose behaviour is predictable and (where it is problematic) how it can be countered.

A number of systems causal maps were drawn during the projects (an example is provided below in figure 5.3)

Figure 5.3: Causal map – Growing the number of Wind Farms

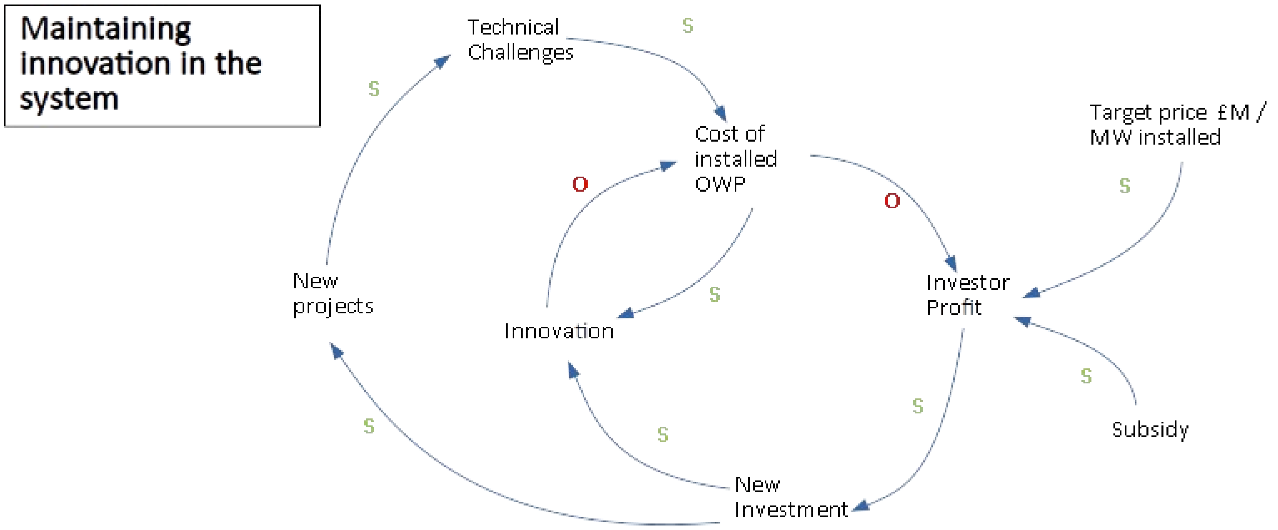


In the shown example there are a number of reinforcing loops (iteration of activities that promotes continued growth) e.g. between ‘invest in OWP’ - ‘build OWP’ - ‘experience of operating OWP’ - risk in OWP’. In this loop increases in ‘invest in OWP’ increases build, which increases experience which decreases risk which increases investment. Such a loop will continue to grow activity until some other factor limits it.

Similarly the loop leading via government policy (‘risk in OWP’ – ‘negative public view’ – ‘supportive government policy’ – ‘beneficial regulatory regime’ - ‘invest in OWP’ - ‘build OWP’ - ‘experience of operating OWP’) is a reinforcing loop that can either increase or decrease growth: increasing risk in OWP increases a negative public view which decreases support thru’ policy, which reduces the benefit in the regulatory regime, which reduces investment, which reduces the build of OWP, which reduces the experience of operating OWP which increases risk.

Figure 5.4 below shows a causal map relating to the behaviour of innovation activity and project investment.

Figure 5.4: Causal Map – maintaining innovation



In this causal map one can see a core balancing loop where increasing innovation reduces the cost of installed OWP which in turn reduces the drive for innovation. This is counteracted by a reinforcing loop between innovation – cost of installed OWP – investor profit – new investment where new investment will drive increased innovation which reduces installed cost which increases returns which increases investment. This shows that innovation investment has the potential to switch between a relatively stable level and accelerating growth.

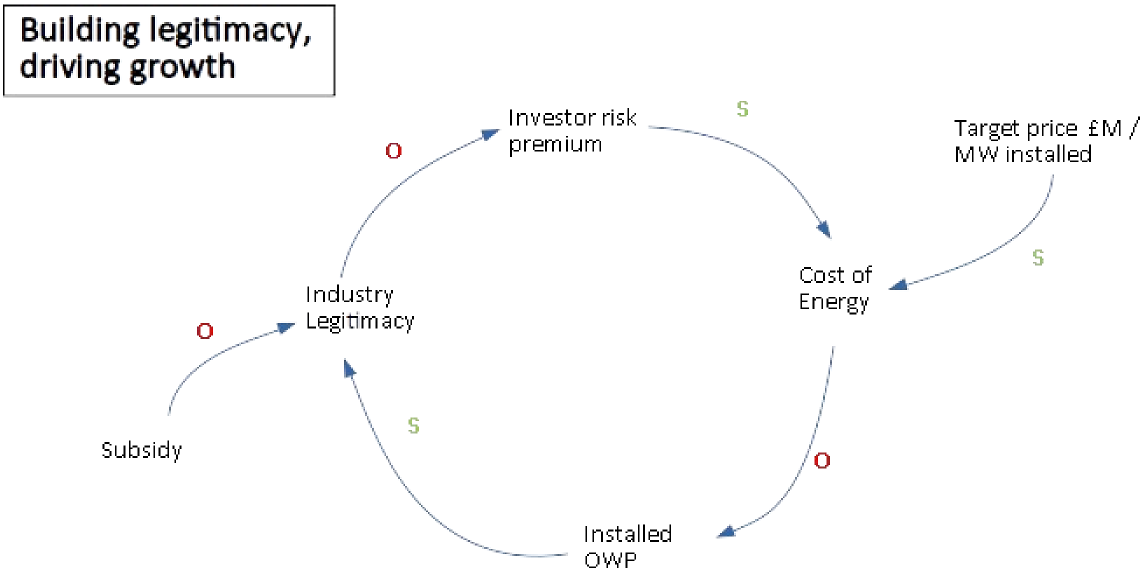
Such analysis helped build an understanding in the industry for the author and highlight more complex ways in which the industry might operate.

In particular, it became clear that there was a causal loop between the drive for legitimacy and growth in the industry. Existing literature is clear that a focus of activity during emergence is to build legitimacy. It became clear that growth was used by participants as a measure to build legitimacy.

These elements were linked by the risk premium that was embedded in early finance packages for construction, that in turn had a significant impact on the levelised cost of energy (LCOE) for the projects. The external setting of a target LCOE supported legitimacy where projects could be seen progressing towards it, and the level of subsidy necessary to make a project economically feasible reduce the legitimacy of the industry.

This is shown in figure 5.6 below.

Figure 5.5: Causal Map – legitimacy & growth



This lead to the insight that the emergent industry driver (of legitimacy) and the indicator (of growth) were not case and effect but linked in causal loop where legitimacy drives growth and growth drives legitimacy.

5.2.3 Ways of engaging with the industry

Extant research into emerging industry describes how drivers such as entrepreneurialism and policy lead to industry emergence. This study of the industry during emergence offers the opportunity to observe how such drivers occur – how actors engage with the industry.

In the 30-year retrospective addendum to his book (Checkland 1999), Checkland argued for 2 modes of use of the Soft Systems Methodology; mode 1 – prescriptive and mode 2 – internalised. This recognised that formulation of SSM pushed a 'how to' focus on the methodology's description. As practitioners become more experienced with SSM, it is the inter-play between models and real world that becomes more important – the *process* of developing models builds understanding (rather than the model itself); taking action and observing outcomes promotes learning about the real world that can then be modelled.

This internalised mode of SSM was observed in the way institutions engaged with the wider industry. Interviewee 'C' described their role as helping to create an industry (the outline aim of this rexearch). Asked to describe how the interviewee approached the task they responded;

"... talking to the senior guys interested in the industry (developers and tech). Look at barriers to getting full potential [of the industry]. *It wasn't the technology. The issues were scale and delay around the processes that put the projects together.*

You could see this was eminently doable – nothing had to be really invented to get cost down.

[There was a] c*ollegiate willingness across all the industry that if we did pull together we could actually achieve all this stuff – working closely with government, working across the supply chain."*

This can be taken as describing an internalised process of iterating between where the interested parties and technologies stood (real world) and what could be (conceptual models) to select actions that would bridge the gaps i.e. SSM mode 2. Key elements being brought out are a common vision *'see this is eminently doable'*, a shared agenda *'scale and delay around the* [project] *processes'* and a commitment to work in partnership *'collegiate willingness across all the industry'*.

The goal of this research has been to observe, rather than influence, the industry during its emergence. The compatibility of the SSM systems approach with the ways actors did engage with the offshore wind power industry does suggest SSM as a way to engage with future emergent industries.

5.2.4 Behaviour of the industry as a system progressing to self-sustainability

Reviewing the literature of systems thinking surfaced the concept of 'viability' for systems. This was tangentially addressed in case literature via the consideration of impact of policy and the 'Empty Category' work of Edman and Amidjian (see Edman and Amadjian 2017).

The concept was explored in two branches of systems theory – Stafford Beer's Viable Systems Model and Millers Living Systems Theory. Of the two approaches, Beer's VSM was shown to have most success in practical application.

The following table (table 5.4 below) sets out how the sub-system definitions used to describe the Offshore Wind Power industry can be accommodated within the VSM. Doing this identified gaps between the expected VSM sub-systems and the previously identified industry sub-systems. The broader industry activity was then reviewed to identify if any activities were being undertaken that fulfilled the expected role.

These systems can then be portrayed diagrammatically as in Figure 5.5 below.

Table 5.4: VSM sub-systems and offshore wind power

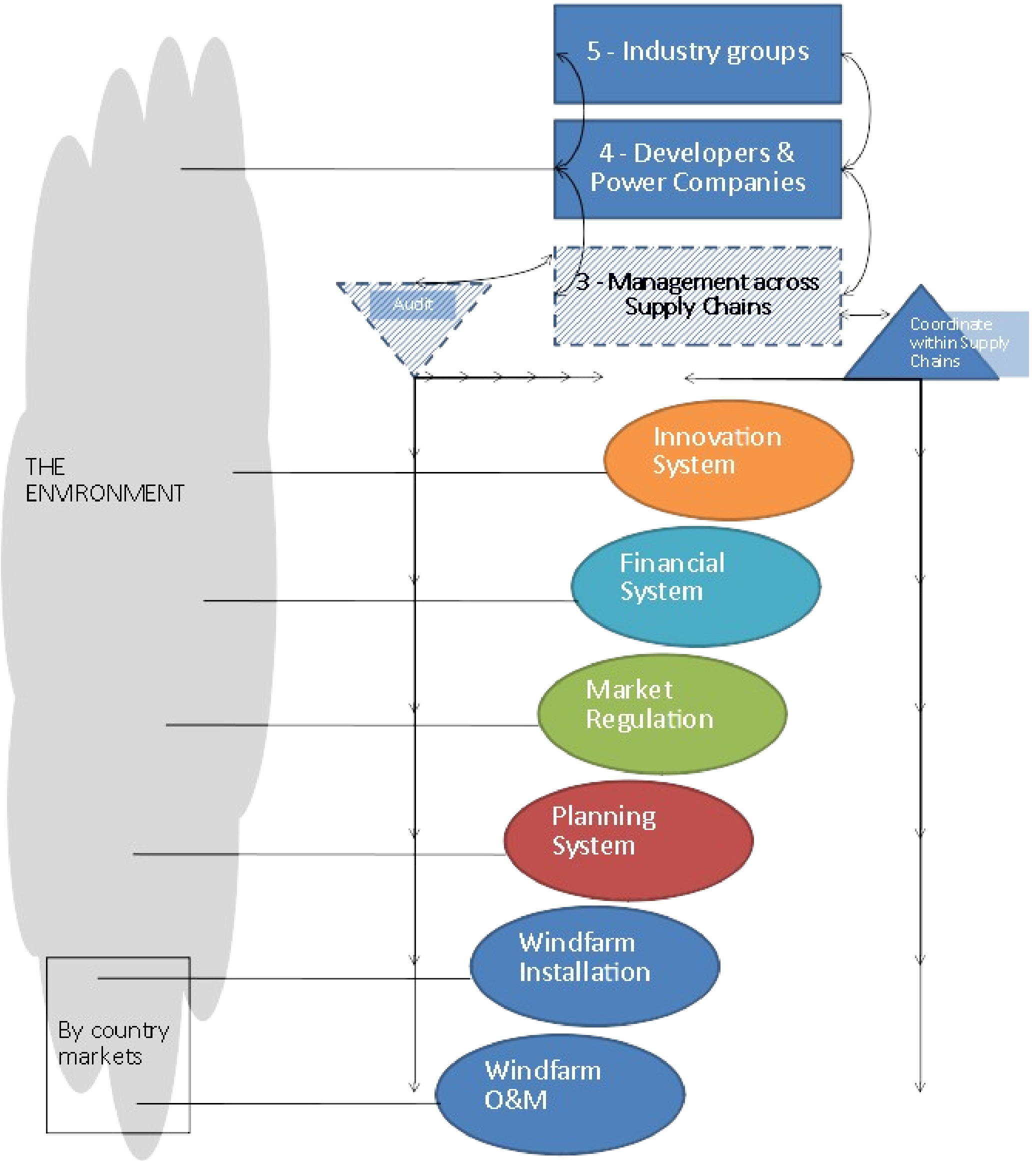
	VSM definition (Bititci et al 1999)	**OWP System**
System 5	The boss. This system sets the direction, the policy and strategy of the organization.	Industry groups discussing and acting on consensus items
System 4	The developmental system, which concerns itself with the external environment and the future. Its focus is on improvement.	Developers and Utility developers aided by specific support programmes
System 3	This represents the tactical management system, which manages the operations of the system 1s.	*Problematic*
System 3*	A subset of system 3 which bypasses system 2 and provides a direct audit channel between the system 1s and system 3.	*Problematic but can be considered to include reports from Government, Industry body, consultancies etc*
System 2	The supervisory system, which prioritises and co-ordinates the activities of operational units in real time.	Occurs within individual supply chains by system integrators
System 1	Operational units	Market reform, Planning, Finance, Innovation, Installation, Ops & Maint

The observed industry sub-systems all relate to the operational units 'System 1' and their coordination – 'System 2'. There were also clear activities going on that fulfilled the roles of 'System 4' (horizon scanning and improvement) and 'System 5' (direction setting).

The problematic areas lie in the lack of an overarching tactical management process ('System 3') for the whole industry. This occurs along with a weak audit function - although the typical outputs of such function can be seen, is harder to identify when or how a joint industry decision was made on what to audit.

The diagram in figure 5.6 below shows how the offshore wind power generation industry may be mapped to the VSM.

Figure 5.6: Offshore Wind Power as a Viable System



Consideration of what might be a ‘system 3’ for a whole industry does suggest notionally practical solutions. The function of the ‘system 3’ as identified in table 5.4 above is to manage the ‘day to day’ performance of the operational units (this may be a different timescale in practice such as week to week or month to month). In the case of OWP the operational system that was generally considered to be underperforming by a number interviewees (‘C’, ‘D’ and ‘E’) was the Planning sub-process – in particular the Scottish planning process. The tangible impact of this was delay in projects (and hence increased development costs). There was also an intangible (arguably more damaging) impact was to question whether any offshore wind would be built in Scotland at all.

This suggests that recognising the lack of a 'System 3' for this emerging industry has a diagnostic value – it shows the industry lacks a mechanism to highlight under-performing processes in a way that leads to corrective action (rather than solely blaming).

VSM analysis of the system also considers the 'algedonic' signals that highlight to system 4 and 5 that changes are required (either to address internal non-function / conflict / or other 'failure' or to address an unmanageable environment input). This is the other side of the discussion about the Scottish planning system underperformance – was it signalled in a way the overall system could be expected to respond to? Also, as it should be recognised there was a response, was the timescale for response longer than could be expected?

The signals coming from systems 3, 4 and 5 to be amplified into system 1 action can be identified in the set goal of LCoE reduction (to at least £100/MWhr). This would be clearer if each sub-system could be audited on its intended actions to support. From observation this would look something like:

- Innovation: Turbine scale
- Financial: Reduced risk premiums with experience
- Market Regulation: Increased competition
- Planning: Faster approval process
- Installation: Reduce costs of site development thru' survey collaboration
- Operations & Maintenance: Increase OEE

The VSM provides a functional framework for understanding an emerging industry that adds to the basic understanding of industry sub-systems by considering how they are coordinated and directed without having to consider individual firms.

A systems understanding of viability may help to address the policy issues described by Edman and Ahmadjian (Edman and Ahmadjian 2017).

5.2.5 Summary on observations of an emerging industry

The observation of an industry during its emergence has provided a number of insights. These can be ascribed, in part, to the use of the systems lens for defining, examining and understanding the industry.

The observations point to the need to build a database of such case studies to determine which of the observed behaviours are a regular feature of emerging industry, and which are specific to the industry in question. With a single case it is too early to make such a determination here.

The process of observation is also worthy of brief comment. One utility of a systems understanding of industry is that it affords the opportunity to bring together ontologically opposed analyses in a single *synthesis*. The differentiation between analysis and synthesis is a core principle in the work of writers such as Ackoff and Checkland. Objective analysis of how the industry is performing can be held alongside subjective assessments of legitimacy and identity to produce a synthesis of what the industry is and where it stands.

It is this *synthesis* of an understanding of the whole that gives the opportunity for supporting institutions to make helpful interactions leading to viability for emerging industries. It is also possible the synthesis is helpful at other stages of the industry life cycle not addressed here e.g. staving off decline, accelerating growth.

The discussion of industry, as a system, shows that assessments of viability must always be 'instantaneous' - no assessment can address the possibility of an unforeseen and non-addressable disruption arising after the assessment is carried out e.g. fusion energy becomes cheap and easy. However assessments of viability can be 'meta-stable'. That is to say the scope for disruption is narrow and understood, any realistic disruptions are foreseen and either appropriate risk management strategies are in place or there is sufficient adaptive capacity in the industry to meet the challenge.

The use of systems approaches to understand emerging industry contributes practical tools to support the contemporary assessment of both emergence and viability.

5.3 Generalizability of the knowledge contribution

Generalizing the findings of exploratory research is always a challenge, more so where the research is focussed on a single case. This section will consider the scope for generalizing this research and outline why there are grounds for considering the findings beyond this single case.

Key aspects of the case that underlying theory identify as particular to the case are as follows:

- It is from the emergent stage of the industry life cycle – relevance to later life cycle stages is not explored

- The case is of a Complex Product System industry – its relevance is to similar industries rather than mass manufacture industries or service industries.
- The case is of a regulated industry supported by government subsidy. Although this case seems very specific, it is implicit in the research question that some form of support is applied to industry in its emergent stage.
- The nature of the end ‘product’ is that capital costs are heavily loaded to the commissioning stage, running costs are comparatively low thereafter. This investment pattern can be expected to have had an impact on how the industry developed and so case findings. This pattern is, however, not unique to this case – other infrastructure and CoPS projects are similar e.g. high speed rail, electrification of inter-island ferries, mobile data networks.

There are reasonable grounds to consider that the research findings have applicability beyond the narrow case considered. As this discussion chapter shows the review of the case findings with existing theory shows a strong general congruence with theory – such findings that contradict existing theory are likely to be features of complex product system industries (e.g. role of a dominant design and the nature of innovation) and as such build upon the existing knowledge base rather than change it. Other findings suggest that drivers have had less prominence in this case (e.g. is legitimacy something to be pursued in its own right, or the natural outcome of consensus building around purpose?). Such findings are not driven by specific ‘in case’ factors and can reasonably be expected to be relevant to CoPS industries, thereby extending the current knowledge base to cover such industry.

Generalizability is also supported by the use of the ‘systems lens’ in which it is the interactions of system elements that carries most importance, rather than the internal workings of the elements. As such the systems tools used are not tied to the the specifics of the case and can be expected to have general applicability e.g. the maturity model to support assessment of emergence, the Viable System Model structure looking at viability.

6. A framework to answer the original question

As the discussion chapter shows this research has been able to add to the existing knowledge base on the drivers for and indicators of, emergence in new industries. By observing the industry during its emergence and considering how the actors in the industry acted to establish offshore wind power as a new industry, insights were gained that suggest a generic way to support new industries may be realistic.

These insights were gained via a ‘systems’ view of the industry. This chapter aims to set out a framework that brings together the insights in a coherent whole. This framework represents a next step on the answering of the question that started the inquiry. It is recognised that the framework cannot be validated without a number of new industries to work with, however it is given an early test by using it to critique a related industry that did not achieve emergence (wave power).

6.1 The framework scaffold

The original question was *‘How do we create a new viable industry?’* and consideration of this notion highlighted a number of complications:

- Complex adaptive systems are not created – they emerge
- Who is the ‘we’ implied by the question
- Viability is hard to predict – it is often only identified by long historical review

Addressing the problem of creating complex systems is a core part of modern Systems Engineering approaches (see Sillitto 2016 for an exploration of Systems Architecting approaches). The architecting approach has an underlying principal which is to design for intermediate structures that will allow the final system to emerge without undue constraint on the details of the system. In systems engineering terms this is often described as designing for the interfaces.

This concept forms a key part of the framework described here with the idea of ‘intermediate forms’ as its ‘designed’ element. The design intent is to put in place the structure that will allow emergence of a viable industry without constraining the form which that industry will take. The term ‘scaffold’ is used here to denote a difference to the overall framework and also to give the connotations of a 'supporting structure'; once established (emerged and viable) the 'scaffold' is no longer required and can be dismantled (or allowed to atrophy).

The systems review of the case industry suggests the following elements are necessary for the framework:

- A influencing group who are aware of the industry as it stands and who have a credible view of where it can / should / must develop. The 'we' in the canonical question. This group;
  - must have tangible commitment to the success of the industry – either as entrepreneurs / intrapreneurs, business unit leads etc. Career and / or investment is a strong indicator
  - must be credible with any antecedent forms. Where an industry branches from existing activity the influencing group must be seen as credible with players in that existing industry. It is not necessary that antecedent industry actors agree with the vision or rationale for the industry, only that they accept the influencing group is capable.
  - must be credible to any necessary or potential supporting institutions. Similar to the previous point, the influencing group must be seen as capable, regardless of any views the institutions might have about the nascent industry.
  - cannot be an individual or a small grouping. The Law of Requisite Variety indicates the need for a larger group, and the reach and influence of the group is enhanced by being larger. Credibility (identified in previous sections) is enhanced by a larger scale.
  - need not completely agree. A corollary of a larger group is the greater difficulty in gaining agreement. Agreement is not necessary in detail, only in broad terms. Individuals may chose to address challenges in different ways, so long as the broad areas of challenge are commonly understood. Indeed a *variety* of ways of tackling issues improves viability.
- An articulated reason for the industry to exist. It is an aphorism of systems is that the Purpose Of a System is What It Does (POSIWID). This is intended to identify that regardless of initial intent, a system will evolve its purpose over time and this purpose can only be gleaned by observing the operation of the whole. In the initial stages a clearly articulated reason for the existence of the industry helps set the direction of this evolution.

- A starting ‘model’ for the industry system (see below). This system model can be expected to change over time, however starting from a common base will help organisations have a consistent view of the industry.
- An articulated method of fast and accurate feedback on system operations. This can be considered part of the starting model. It is a separate element as even where there is no agreement on an initial system model, there can be agreement on what information can be shared, what external activities should be monitored and which supporting institutions might be engaged with.

The analysis and discussion identifies that the systems framework for the initial model should be derived from Beer’s Viable Systems Model (VSM). As argued in the discussion chapter, this framework has an explicit goal of describing a system that is capable of interacting with its environment in order to ensure ongoing viability during changing circumstances. Miller’s Living Systems Theory is the alternative systems framework but has significant complexities involved in utilising it in a ‘design’ mode.

In following the VSM, the initial model needs to consider:

- The identity of the operational units – human activity systems in SSM terms. From the experience of the research case, these should not be the individual supply chains, but some common operational activities inherent across all the core organisations. The system description of offshore wind power generation is appropriate as a seeding point for complex product system industries i.e. the following sub-systems should be considered; market system, planning system, innovation, financing, build, run
- A mechanism (or mechanisms) for coordination between the operational units. Where the operational units occur within individual supply chains, the coordination activity broadly happens within these supply chains (e.g. financing, planning and build will naturally be balanced for each project by its system integrator). A level of collaboration is desirable between supply chains to identify a somewhat common way of approaching each activity.
- A direction setting mechanism. This takes the role of System 5 in VSM for an industry. The situation gives less control than a single organisation. The mechanism should consider inputs from horizon scanning and audit and set out where the industry (believes it) should go. This should happen either periodically (say annually) or in response to specific environment change.

- An intelligence gathering and distillation mechanism. In the VSM for a single organisation this is the horizon scanning and scenario building process (system 4) that feeds into the (system 5) strategy process or identifies short term reactions to the ‘inside and now’ process. For the industry, it forms a key part of the ‘self-awareness’ of the industry as a whole. Structures which can provide this include trade organisations, lobby groups, special interest media platforms.
- The ‘inside and now’ system in VSM (system 3) is the most problematic system to identify and design for an industry. The implication from VSM is that this system looks for out-of-control conditions in the operational systems (either by being alerted via algedonic signals, or by considering audit results) and determines counter-actions. In the example of the case study, the lack of a coherent system 3 allowed the planning sub-system (within Scotland) to become out of control. It was resolved in time from within the sub-system (through regional government action). The lack of an industry response reduced participant’s belief in the system overall. For this framework it is proposed that an involved (but not directly acting) entity takes the role of considering ‘inside and now’ for the industry. This is discussed more below.
- The audit function in the VSM (System 3*) is required to provide additional control ‘variety’ over and above the coordination and ‘inside and now’ activities. In practical terms it identifies is who reports what when, and to whom. In the case study example this audit function was closely tied to the pre-eminent industry purpose of reducing levelised cost of energy (LCoE) to a target figure. The function is intended to deliver both regular and sporadic reporting. Agreement on what this looks like is a first step towards industry viability.

It is an axiom of systems that it is hard to ‘see’ the system when you are in the system. This leads to a number of systems tools e.g. value stream mapping and causal maps that help visualisation for individuals or groups inside or outside the system. Deming goes further in his System of Profound Knowledge and says that ‘*… knowledge comes from the outside, and by invitation. A system cannot understand itself.’* (Deming,1998). At the core of this statement is the concern over bias from those ‘within the system’.

This points to the need for an independent entity (individual or organisation) to play a role in supporting industry emergence. This role is analogous to a non-executive director on the board of a company ‘*to provide a creative contribution to the board by providing independent oversight and* *constructive challenge to the executive directors'* (IoD, accessed 7th March 2019). The entity must be as committed to the success of the industry as the core businesses and not have any conflicting interests. It is not expected to devote all its efforts to this role, but it should be a natural extension of its normal operation – the role is described as a 'critical friend' in the schema in figure 6.2 below.

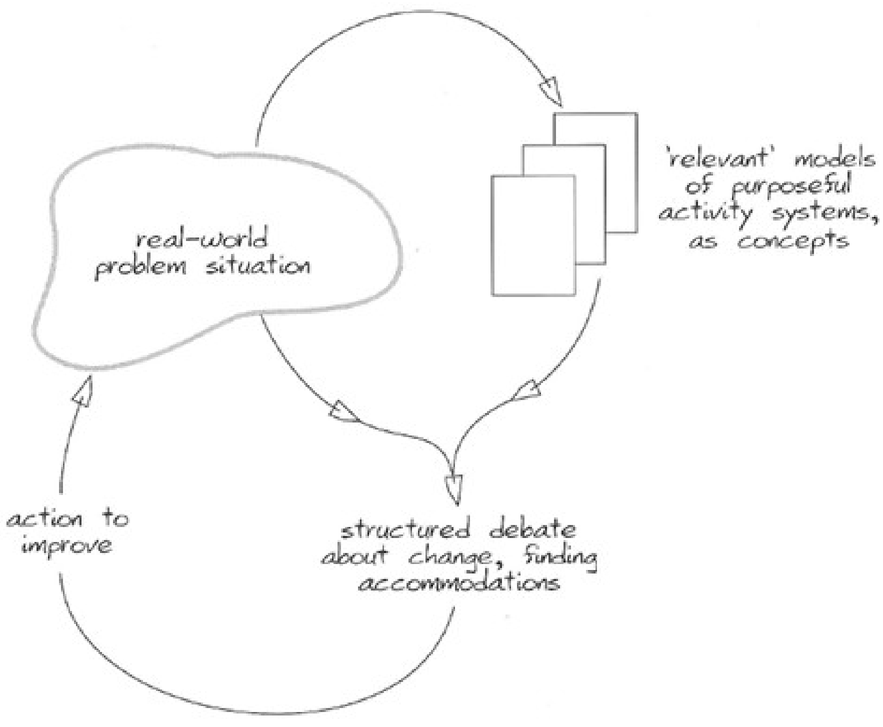
Within the case study industry a number of organisations may be considered to operate in this way (e.g. Scottish Renewables, RenewableUK, ORE Catapult). A critique of these organisations' ability to fulfil the role would be that they either lacked the 'challenge' element (industry bodies) or their remit was too narrowly focussed (ORE Catapult). This would not be an insurmountable issue and could be addressed by commonly understood 'rules of engagement'.

6.2 Animating the scaffold

The scaffold described above requires some 'rules of engagement' to make it dynamic. The discussion in the previous chapter points to the utility of Checkland's Soft Systems Methodology in engaging with an industry once a collective forum is identified.

For this framework it is proposed that SSM is applied in 'mode 2' (internalized form) – only moving to 'mode 1' (prescriptive) where participants require it e.g. need for structure during uncertainty. Checkland conceptualised a learning organisation following the methodology as shown in figure 6.1 below, and the use of SSM here is proposed in this spirit.

Figure 6.1: SSM description of a learning organisation.



As such the following list is an ‘agenda’ for early development rather than a process to be followed in a stepwise manner:

- **Establish identity.** This implies a group with common interest agreeing what the industry is. This may be individuals from an antecedent industry, or technologists pulled together by promoting industry body or any individual or body with an interest. The trigger for this is likely to be a discontinuity recognised by all participants.

  This seed group needs to consider who else might be involved – *establish the system boundaries.* As with the case this can be considered as a nested group of levels – analogous to the MoSCoW method (See Clegg and Barker, 1994).

- **Establish rationale.** What is the reason for a separate industry to exist? In the early stages this may well be unclear. An example from the case study is that offshore winds are stronger and more prevalent, planning is easier if you are out of sight, the marine engineering required is well established in the UK. In later stages the rationale had moved towards offshore wind can be deployed at affordable levels and in scales greater than onshore.

- **Problems / situations to be addressed in the first case.** Given the use of Checkland’s SSM a natural start point is to build consensus is the CATWOE root definition for the industry;

  - Customers: How clearly are these defined and understood? For offshore wind power the customers were initially the electricity retailing organisations (who required the ROCs). Developer organisations may also see the generating companies to whom developed projects would be sold on as customers.

  - Actors: Who is involved in the industry (and what roles they perform). This review may identify others who should be involved in the core group, or be a repeat of this.

  - Transformations: What does the industry ‘do’ when considered as a ‘black box’ i.e. what comes into the industry and what leaves. As an example from offshore wind inputs are steel, concrete (and other raw materials) and outputs are wind farms, electricity, ROCs (while relevant).

  - Weltanshauung: In Checkland this describes the worldview that gives meaning to the system. It can be helpful to consider conflicting worldviews here as this will help to address legitimacy for the industry. The world view is closely aligned to the industry rationale but is more intangible. As an example for offshore wind power the positive weltunshuumg is that harvesting wind is a good thing, zero carbon power generation is necessary etc.

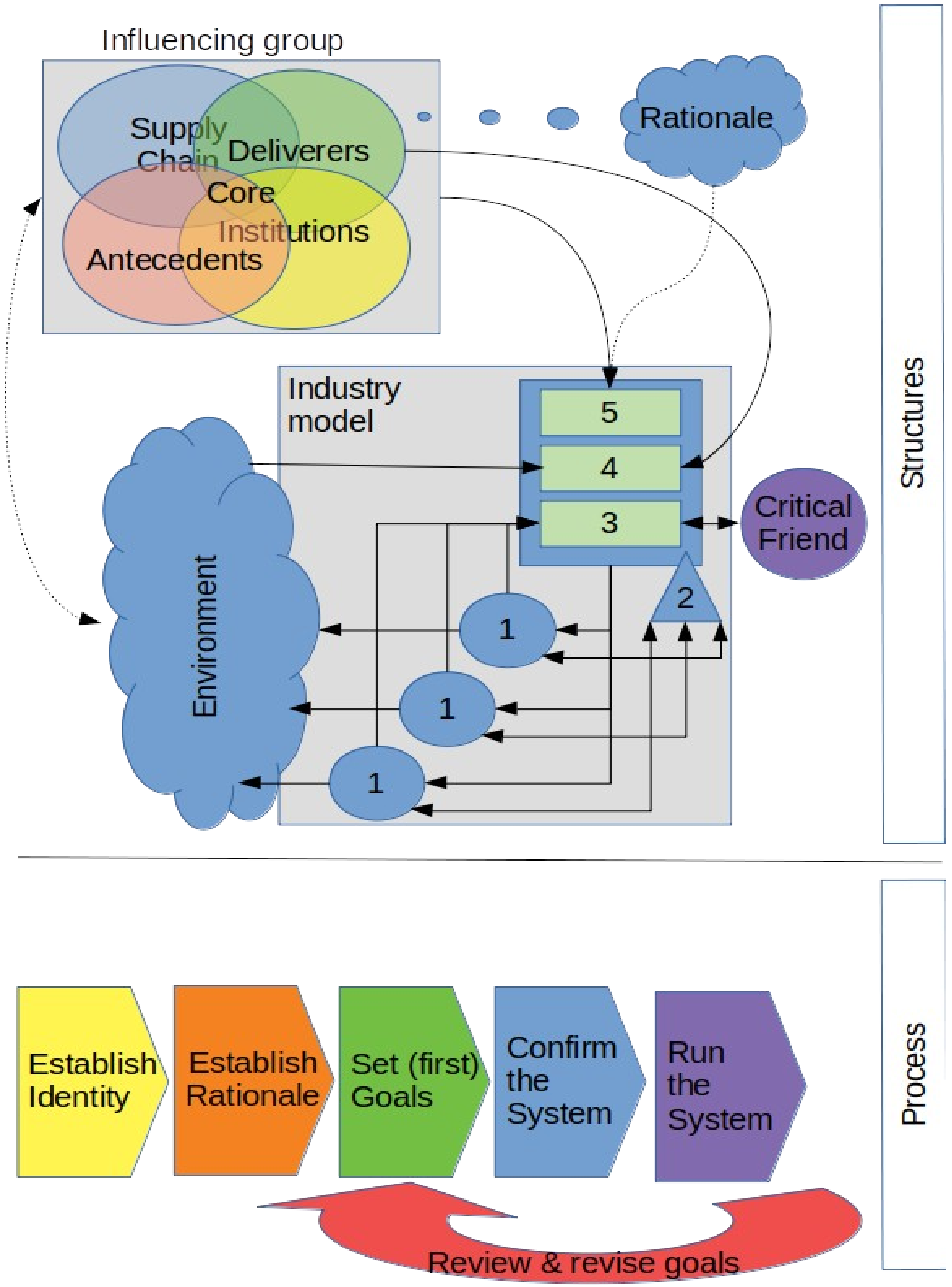
  - Ownership: This element should consider which bodies or individuals have ownership roles in the industry. This can be ownership of tangible elements e.g. the seabed for offshore wind, or of intangibles such as intellectual property (patents etc.) on the underlying technology. Consideration of the ownership will help identify individuals or bodies who need to be supportive of the industry, if not actively involved.
  - Environment: What are the constraints and limitations that will impact the industry and influence its success. This may be related to the ownership question, or describe some wider unknown in the wider economic landscape.

- **What does the industry look like now?** This is the stage where the VSM-based systems model is taken as a start point. This will describe 'relevant model of purposeful activity systems' as shown in figure 6.1 above. It may also include descriptions of information flows and relevant measures that may be collected.
- **What are 'we' going to do about it?** This activity is about building a consensual view of what desirable actions may be taken – either collectively, or as individual organisations. This does not require complete agreement on the actions, nor should it involve negotiated plans - *'if you do this then we will do that'* as outcomes are likely uncertain and failure to keep up a bargain will erode cohesion in the group.

This agenda implies a hosted meeting, and this may be the first action of the interested / auditing body, or a third party with remit to support development as exists within the UK (Scottish Enterprise in Scotland and various Local Development Agencies in England and Wales). Where the industry is branching from an existing one, the meeting may take place within that antecedent industries meeting structure. Where there is no single meeting the same outcome can be arrived at by a number of linked conversations.

The following diagram (figure 6.2) sets out this framework as a single schema.

Figure 6.2: Framework for supporting the viable emergence of industry



6.3 Validating the framework

6.3.1 Process for applying the framework

Formal validation of the framework would require working with an additional emerging new industry. As has been noted from the beginning, this is a rare thing to have. In the absence of this one can seek to see how the framework fits with previously documented emerging industries not previously used in the research.

Wave power generation is one such industry. It has been subject to recent comprehensive study (Hannon et al, 2017) to understand the performance (and perceived failing) of the wave power innovation system within the UK (and Europe). While the study is focussed on the innovation system support around wave energy it is wide ranging in its consideration of actors and activities. This report was used as a primary source of data on the industry to which the framework was applied. Where questions could not be directly answered from the report, it was used as a start point for internet searches for the industry. Finally, the remaining questions and areas for clarification were explored with one of the reports authors.

Having gathered the data together, a number of conclusions were drawn based on the fit to the framework. These were tested with the industry expert to gain some measure of the frameworks validity.

6.3.2 Findings from applying the framework

1/ Core Group:

The report identifies a number of organisations involved in wave energy.

- **Device producers:** There is a list of 34 operating in UK between 2000 & 2017. 14/34 ceased trading in this period. A number of companies were bought out by utilities who then closed them.
- **Project Development:** A list of organisations is provided with key expertise provided on a consultancy basis, but not as a ‘systems integrator’ taking ownership of delivery. The consulting organisations have other marine engineering interests.
- **Manufacture:** This is mostly contracted out to third parties (electrical equipment manufacturers, fabricators etc.) and a number are identified. As above these have other marine engineering interests.

- **Operations & Maintenance:** No specific organisations are identified. Too early.

From the framework, the core group should come from either the device producers or a development organisation making use of the devices in a ‘systems integration’ role. There is no clear group fulfilling this role that can be deduced from the report.

A review of internet resources identifies the following industry facing organisations, Aberdeen Renewable experts Group (AREG) and Wave Energy Scotland. AREG is an industry membership organisation that is active in a number of renewable technologies including wave power (offshore wind and tidal being the others). Wave Energy Scotland is an offshoot of Highlands and Islands enterprise and was set up with the goal of *“driving the search for innovative solutions to the technical challenges facing the wave energy sector*.” It has been in operation since 2014 and it includes an advisory group made up of involved organisations (though not device producers).

The renewables industry associations in the UK (RenewableUK and Scottish Renewables) have sections for wave and tidal power in their structures. The apparent focus of these organisations is on tidal energy.

Conclusion: **No coherent grouping of companies exists that aims to advance wave energy as an industry**

Insight 1: **The focus on technical challenges indicates the lack of a dominant design.**

Insight 2: **The lack of development organisations procuring commercial solutions means there is no evolution pressure (selection) on designs.**

2/ Purpose:

The lack of an identifiable industry group limits the potential for a cohesive set of goals for the industry. The AREG and WES sites do have a consistent view of the challenges for wave power – implying these should be the goals for the industry;

- Cost effective electricity generation. In the April 2017 CfD round administrative strike prices for wave energy projects were set at £310 / MWhr for 2021/22 and £300/ MWhr for 2022/23. The May 2019 CfD round sets the administrative strike prices at £281 / MWhr for 2023/24 and £268 for 2024/25. There is no available equivalent of Offshore wind power’s £100 / MWhr in 2020 target.

- Reliable and efficient operation (power take off). This goal demonstrates the relative lack of maturity of wave energy despite its long history. The ORE Catapult report on cost reduction opportunities for wave (and tidal) indicates there is expected to be a trade off between reliability (from simple devices) and efficient (more complex devices) operation.

- Maintainability of the assets

The information available shows a lack of clarity on why wave power should be used. Reports on cost effectiveness talk about the technology as being a long way from its competitor 'offshore wind'. Offshore wind's 'purpose' was to make use of the better wind resource offshore (compared to onshore) and address the difficulty of getting planning permission (by being out of sight). No similar rationale is put forward for wave power.

The third marine energy – tidal stream – has the rationale that while it is intermittent power generation, it is highly predictable (4 times a day) and consistent (tidal stream velocities change only a little). It therefore has a different place in the energy mix from other renewables.

In the meeting with the report's author, he identified that a number of organisations are looking at different potential niche's that wave energy could occupy including:

- Off-grid energy production (i.e. for small island communities)
- Alternate use – desalination (for tropical communities)
- Alternate use – air-conditioning using thermal lift (for tropical communities)

Conclusion: **Wave energy as an industry is held back by a lack of differentiated purpose.**

Insight: **A rationale for the industry is required. If it is not to be the lowest cost, another element must be included**

3/ Shape of the Industry:

The report gives a great deal of detail on the operation of the innovation activity around device research and development. The key activities from offshore wind power can be seen in the wave energy industry albeit with different focus as shown in table 6.1 below.

Table 6.1: OWP derived sub-processes in wave energy industry

Sub-process	Activity in Wave Energy industry
Innovation	Primary focus of activity. Supported by WES, 32 organisations running projects
Market	Crown Estate ownership role, CfD support
Planning	Test sites in place, no commercial developments
Financing	Some involvement
Installation	Part of innovation activity – no current deployment plans
Operations & Maintenance	Part of innovation activity – ad-hoc currently

The over-riding focus of innovation processes is more than just a by-product of sourcing the data from a report on this aspect of the industry. A review of the available information on the internet points to an industry wide focus on developing the conversion devices.

An additional / alternative system tool to help describe the industry is to use the CATWOE headings.

Customers: Utilities, consumers, island communities

Actors: HIE, AREG, WES, marine engineering, science, test facilities, training

Transformation: equipment manufacture, power generation, equipment maintenance

Weltanshauung: there's lots of it, it is non-fossil fuelled, it is out of sight

Owners: Crown Estates

Environment: Need for low carbon electricity, large amount of wave resources

There are no specific conclusions from this element, other than to say the industry is at a very immature level. This was known at the start.

In the review with the report's author, he drew attention to the Marine Energy Accelerator and Marine Farm Accelerator programmes supported by the Carbon Trust. These were intended to follow the pattern of the Offshore Wind Accelerator programme in bringing wave energy technology to a commercial level but were considered to be notably less-successful. This is despite having a similar make up of utilities and device producers involved.

Conclusion: **The industry lacks a grounded market-pull pressure to fruitfully select competing technologies and organisations fulfilling the 'system integrator' role required (as a selector of technologies) for a CoPS industry**

Insight 1: **The customer group could be focussed on island communities.**

Insight 2: **Technology push industries take a long time to emerge**

4/ How does the industry talk to itself?

The report finds that there are active networks across the science, test facility, training, industry and government groupings. It is notable that this activity has been in place only since 2015.

The WES organisation has been holding an annual 1-day conference since 2016. In the 3 years held it has covered the following topics:

- Power Take Off (PTO – 2016, 2017, 2018)
- Novel Wave Energy Conversion (NWEC – 2016, 2017, 2018)
- Materials and Processes (2017, 2018)
- Control Systems (2017, 2018)

There is no discussion of commercialisation in these sessions however it should be noted that these conferences come after the high profile failure and closing of the leading wave energy companies Pelamis and Aquamarine Power. It is reasonable to assume there is no appetite for commercial decisions.

The renewables industry bodies RenewableUK and Scottish Renewables both have wave and tidal energy forums within their structures. As indicated previously, these currently have more focus on tidal stream devices.

Conclusion: **The industry is not (yet) following a coherent agenda in which collaboration is able to play a part**

Insight: **The sharing of information must be purposeful if it is to progress the industry – e.g. cost reduction, problem solving, lessons learned collaboration.**

5/ From the report

The report was also reviewed to explore any elements of the report are not directly sought out by the framework but which may have relevance for the offshore wind case study that led to the original framework.

The report looks at the industry through the lens of the Technology Innovation System (TIS) framework which sets out key functions of a TIS as follows:

- Knowledge development (F1): broadening and deepening of a codified knowledge base
- Knowledge exchange (F2): exchange of information via networks
- Entrepreneurial experimentation (F3): recognising of value in technology and experimenting commercially to realise that value
- Guidance of the search (F4): Pressures to enter a field and pursue particular goals (via policy, technology roadmaps etc.)
- Resource mobilisation (F5): resources such as financial, human, physical that are critical to the innovation process
- Market formation (F6): mechanisms to create niche markets that enable emerging technologies to compete against incumbents
- Legitimisation (F9): granting legitimacy to the technology by strengthening its 'fitness' within the prevailing institutional regime

The report identifies weak performance against indicators of two of the functions, entrepreneurial experimentation (found to be very weak) and market formation (found to be weak). This performance is potentially identifiable with the finding of a lack of clear purpose (value proposition in TIS parlance) from the proposed framework.

The report finds that there was a premature push for commercialisation which focussed innovation activity on later stage innovation. This was based on over-optimistic assessments of how quickly the technology could be commercialised. As it became clear that technical difficulties still had to be overcome and commercialisation was not on the horizon there was significant retrenchment in the industry. This has echoes of the empty category issue of jibiru (Edman and Ahmadjian 2017). The 'category' owners (government) are setting market-pull incentives and setting out defined 'roles' for wave power in advance of developers (entrepreneurial experimenters) finding a niche market with clear end-customers.

It is this 'empty category' finding that helps harmonise the report finding of a push for commercialisation too early, and the proposed framework conclusion that there was a lack of clear 'purpose' for the proto-industry. These conclusions could be considered to be at odds with each other (one saying the technology isn't ready, the other saying a common view of what the technology is for) but in fact these conclusions are compatible – without a clear prupose then the technology can always be considered ‘not ready’.

Insight: **If there is money to be made (via subsidy), competition will give rise to organisations that can capture this (subsidy) money. This need not lead to a long-term viable solution.**

6.3.3 Summary conclusions for applying the framework

As shown above, the application of the framework to the situation of the wave energy industry is able to draw a number of conclusions these are summarised here.

- No coherent core grouping of companies exists that aims to advance wave energy as an industry (rather than as a technology).
- Wave energy as an industry is held back by a lack of differentiated purpose. Some opportunities do exist but the lack of the core group means no clear purpose arises.
- The industry lacks a market-pull pressure to fruitfully select competing technologies – such a signal would come from organisations fulfilling the ‘system integrator’ role (as a selector of technologies) for a CoPS industry.
- The industry is not (yet) following a coherent agenda in which collaboration is able to play a part. This is a similar conclusion to the ‘purpose’ conclusion above, but points towards technologies rather than markets.

These conclusions are compared and contrasted with the conclusions of the report summarised in table 6.2 below.

Table 6.2: Comparison of Wave energy report findings and framework conclusions

Wave energy report findings	Framework alternative
Wave energy's failure to reach market can, in part, be attributed to weaknesses in government and industrial strategy … most notably a premature emphasis on commercialisation and a lack of knowledge exchange	The lack of a 'dominant design' selected by a system integrator stalled commercial development. Lack of a coherent agenda in technology development also hindered knowledge exchange.
These weaknesses have resulted in poor performance against key innovation indicators (market leaders entering administration, a fall in capacity, lack of convergence around a dominant design)	A systems view would point to there being a circular cause and effect loop here. The need for a 'lowest risk' (dominant) design for investment is suggested for CoPS.
The downturn in UK wave energy innovation performance led to multi-national incumbents and investors withdrawing from the market. This led to a review of policy mistakes.	This can be expected from earlier studies e.g. Argawal et al 2014 where an early shake out occurs.
The lessons from the learning have resulted in a reconfiguring of the UK wave innovation system to address issues. These include reconfiguring RD&D programmes (government support), formation of new actor networks and commissioning of test infrastructure.	The framework suggests that effective actor networks are an important aspect for an improved wave energy industry system. The value of the RD&D programmes and test infrastructure would be determined by the actor networks.
As it stands now the wave energy innovation system is better placed to deliver a commercial device but disruption is likely as a result of wider political developments (e.g. Brexit).	The ability of the wave energy system to find a way through these disruptions is a key test of viability.

The actions suggested by the conclusions and insights from using the framework are;

- Institution mediated workshop of technology producers, supporting agencies and 'customer' representatives to identify ways forward (where the capability has unique potential) and markers of progression e.g. technology reliability, installation costs etc.
- If the technology is still at the exploration stage in reality, test cases should be run against proposed use cases e.g. verification (the technology did what was intended or not) and validation (working as intended the technology got these real world outcomes). This would help identify an addressable market for the technology.

6.4 Discussion of Framework Validity

Clearly the above process cannot fully test the validity of the framework. There is no direct interaction with the industry and the time and process based elements of the framework could not be trialled. Despite this the framework is able to provide some insights into the activity that give an alternate view on the issues identified with the wave energy industry. This in turn does suggest, at the least, that the framework can provide early insights that will support the development of an industry in its pre-emergence state.

The congruence of the sub-processes identified for the offshore wind power industry via a grounded approach with the Technology Innovation System functions used within the wave energy review underlines issues that will occur with systems approaches. An axiom of such approaches is that *'systems are in the eye of the beholder'* and so the same 'whole system' may be modelled differently by different observers. Where this modelling is for different purposes, as in this case, there is no immediate difficulty. Where different observers with the same intent construe the same system differently, then there will be the potential for conflicting understanding.

In this case study, the selection of underlying sub-systems was carefully debated and alternatives considered (see section 4.3). Any future user will need to take the same care in the construction of the system picture for their case. This difficulty can also be seen as an opportunity to engage in useful dialogue with the industry in focus. Any disagreements with the system picture are a route to a better understanding of the industry by its participants, and a more credible model for the industry activity.

For the validation case the offshore wind sub-systems were not an appropriate start point for the systems picture, given the information available. An alternative systems form (CATWOE) that was more appropriate was available, and could be applied.

6.5 Summary

The research has given rise to a framework that has been shown to be applicable to a related case.

The framework is not an infallible algorithm and will require the users to be comfortable and proficient with systems thinking approaches to situations. It does not, however, require users to develop entirely novel skills.

The framework can be used in its current form as the start point in an action research approach to support future industry emergence. The most suitable candidates will come from industries with related characteristics:

- infrastructure or complex product system industries
- utility-based industries
- industries driven by decarbonisation policies

7. Conclusions

7.1 Revisiting the aim, objectives and research questions

The stated aim of this research was to consider how involved agencies could support the emergence of viable industries. This aim grew out of a concern that a ‘wait and see’ approach to industrial change would not be sufficient to meet the pace of technological and global market change, and that previous attempts to foster particular industries had not resulted in long-lasting and thriving industries in the UK.

This concern is now compounded by the increasingly urgent need to move whole economies to a low green house gas production basis very quickly, and a zero carbon basis within current planning horizons (2050 is often used as a goal date).

The overall objective for the research is to develop a framework for interaction that aids the emergence of an industry in a state that is ‘viable’. In order to achieve this end goal, it is recognised that knowledge building is required on the definitional parts of this goal:

- How to identify an industry during the pre-emerged state
- How to assess when the industry has reached a stage of emergence
- How to assess the viability of an industry at a given point in time

The existing literature was reviewed in 2 stages; firstly exploring the under-pinning theory related to industry emergence and secondly looking at the case based research on industry emergence. A number of limitations and gaps were identified with the research that has taken place to date.

A fundamental driver for this research was that previous case research on emergence has only been undertaken on industries that have already emerged. Related to this, is the lack of published work on the identification and definition of industries during the pre-emergence stage – this is not a problem if the industry being researched has already emerged and its identity and membership is self-evident. Review of early theory literature on definitions of industry showed this to be a non-trivial issue. A number of the case literature papers identified and explained the strategies used by the authors to avoid the issue.

The review of the theory literature showed a number of individual drivers that impact on the emergence of industries. This work is critiqued as it fails to build to a whole picture of industry emergence and, while it may suggest individual elements that are beneficial, it does not address how such drivers may interact. A final critique raised in the literature itself is the focus of the work on mass manufacture industries leaving complex product systems industries and service industries still to be researched.

The interaction of driving is a feature of systems inquiry. More recent literature on industry change uses systems approaches to develop understanding of developing industry activity and strategies for interaction (principally through an ecosystem and evolutionary metaphor). This led to the insight that using a systems lens for the observation of an emergent industry offered the potential to address the definitional issues of industry raised in the literature and offer a more complete understanding of the industry as whole with the complex interaction of pre-identified factors. System Thinking introduces the concept of 'viability' for systems.

The aims and objectives were then coalesced into the following concrete research questions that would drive the research design, data collection and subsequent analysis.

1. Does OWP follow the pattern of emergence identified in the literature?
2. What can be learned from the observation of an industry during its emergence?

The strategy to be followed in addressing these questions required careful consideration of methodology. Addressing the gap of the lack of research on emerging industries 'in-situ' led to the practical selection of a single case with all the attendant issues of research reliability and validation.

Given the lack of prior research conducted in a similar situation, it was clear that the research approach should be grounded. This stance also needs to be balanced with a recognition of the value of existing theory applied in other contexts and of the researcher's long industrial experience – a pure 'grounded theory' is not appropriate. The research design recognises the ontology of this research as subjective on balance, with a 'critical realist' epistemological stance, and the design is constructed using an interpretive methodology.

A key strategy in the research that aimed to enhance the reliability of the study was to build a high degree of triangulation into the data collection and analysis. Three separate data collection activities were undertaken, each with their own analysis and interpretation. These were;

- a longitudinal observation of industry via the annual conference
- collation of industry output from published (government) sources

- interview with carefully selected participants following a structured protocol

A foundation of the analysis was to consider whether the case represented a new industry, rather than e.g. a series of projects for an existing industry. This was how sceptical observers of the initial industry stages considered it to be. The ability to counter such arguments is a corollary of identifying the emergence of a new industry.

In parallel, the analysis considered the evidence for the drivers and indicators of industry emergence that pre-existing literature had identified for mass-manufacture industries, and how such drivers and indicators operated within a complex product system industry. A number of the drivers were found to act in the same way in this case ; examples are 'branching' of the industry coming from a discontinuity; entrepreneurial action having a key role to play and isomorphism having a role to play. Other drivers were seen to have a more nuanced impact where the driver and the indicator interacted more as a causal loop e.g. legitimacy driving growth and growth driving legitimacy. Key findings related to the indicators of emergence which were seen to be different for offshore wind power. Particular examples are timing of the emergence of dominant designs and the relative rate of firm fall-out.

The industry under examination was supported by a number of institutions. Observation of the industry during its emergence stage suggested how the interaction of policy actions taken by agencies may either support emergence of the industry or detract from it; and how such actions may separately support viability or detract from it. This element of the study led to the insight that the emergence of an industry and its viability are different.

The discussion chapter considers the generalisability of the case findings, recognising the limitations of a single case study, within a perceived different class of industry. The findings that are contrary to existing literature have the greatest general application as they show that emergence can follow a different profile (in particular with reference to existing indicators of emergence).

The use of the systems lens for the contemporary observation of an emerging industry provides insights into the behaviour and interaction of key elements of the proto-industry. These insights suggest ways in which a framework for support of such a proto-industry might be constructed.

This leads to a proposed framework for interaction with industry. This is not formulated as specific for a complex product system industry, but it is recognised that its applicability is rooted in this context. The framework covers supporting structures for industry interaction and the initial 'agenda' of action that could be followed. The framework is constructed in the expectation that it will evolve with the industry and either become irrelevant or be absorbed into other structures.

Chapter 6 shows how preliminary testing of the framework was undertaken with a prior documented case. The framework was able to suggest previously unexplored elements of the overall endeavour that could be seen to have stopped wave energy emerging as wind power has. The framework also offers suggestions on ways to tackle this.

The framework is put forward as a starting point for development through action research based interaction with potential new complex product system industries. The detailed case study could also provide a template for researchers looking at other emergent industry cases e.g. in a service sense, or mass-manufacturing.

7.2 Assessing Research Quality

Chapter 3 sets out how the research design forms the basis for assuring research quality by integrating the four factors of internal validity, construct validity, external validity and reliability. As the chapter discusses this is a non-trivial issue for single case research in general and the topic being investigated in particular, with its mix of highly ‘objective’ activity (investment, build of turbines, scale of projects, time to complete) and ‘subjective’ drivers(expectations of future, interpretation of policy signals, determination to succeed.

The advice of Yin (2003) and Gibbert (2008) is followed in constructing the research design and table 7.1 below summarises how this has been applied.

Table 7.1: Assuring Research Quality

Tests	Case Study tactic	Phase of research	How has this been fulfilled?
Internal Validity	Causal relationships	Data Analysis	Deriving causal maps from the observed phenomena
	Pattern Matching	Data Analysis	Pattern Matching from the case to existing literature
	Theory triangulation	Data Analysis	Theoretical triangulation via different systems approaches
Construct Validity	Clear chain of evidence	Data Collection	Multiple sources of publicly available data identified
	Triangulate the data collection	Data Collection	Three different perspectives and data types used to construct case
External Validity	Use theory in single case study	Research design	Case findings compared to existing theory and
	Use replication in multiple cases	Research design	Compared to published second case (wave energy)
Reliability	Transparency	Data Collection	Semi-structured interview protocol followed
	Replication	Data collection	Case Study data sources publicly available

7.3 Research Significance

Whilst it is recognised that the emergence of new industries is a rare occurrence in daily life, they contribute to a significant level of change over the course of a lifetime. There are also a number of global level trends that, at the least, suggest that a greater level of industry change is now underway. These are exemplified by;

- de-carbonising of economies – one of the drivers for the industry researched here
- digitalisation of industry – the technologies grouped together as Industry 4.0 have significant potential to greatly change the configuration of industries if not to create whole new industries
- loss of productivity growth in G7 economies – there has been a 10 year lull in the growth of productivity in the G7 economies. This has direct impact on medium term prospects for economies and ways to counter the trend are being actively sought
- steady state economies – as a counter point to the previous trend, the environmental lobby is looking to move the world towards non-growth to preserve resources in a closed system

These trends require better understanding of new industry emergence, particularly where there is a need to actively encourage the emergence of particular industries. Existing research has already developed a rich understanding of single factors that have an impact on industry emergence. This is being extended by ‘ecosystem’ approaches that recognise the complexity of the situation.

The ecosystem metaphor as a way for new industries to emerge has a number of implications;

- recognition of the discontinuity – there must be some signal that a discontinuity has happened that can be taken advantage of. Entrepreneurs prefer that few people notice this
- lots of variety production (scale of economy) – evolutionary systems, by definition, require a lot of variety to experiment towards the ‘fittest for purpose’ solution
- acceptance / tolerance of majority of experiments failing – it is an axiom of such systems that most experiments fail, and so there must be a tolerance of these failure (i.e. companies & jobs) from all the stakeholders
- evolved solutions are not necessarily efficient solutions – there is an inherent ‘satisficing’ behaviour to ecosystems, they generate ‘good enough’ solutions, eventually. This may happen quickly or take a long time and may result in solutions that are both clearly inefficient, and hard to change.

The existing formulations also stop short of providing any guideline to purposively interacting with a particular industry to support it emergence.

This research offers a novel way to approach this topic that builds upon the existing streams of detail understanding of single factors and group (industry ecosystem) behaviour to present a framework for interacting with a particular, nascent industry to support its emergence as a viable entity.

7.4 Novelty of Research

The novelty of this research lies in the following 2 key areas.

1. Observation of an emerging industry during emergence. Although the literature review was able to identify a number of cases that investigated the emergence of an industry, these were all carried out after the industry had emerged. This limitation to the previous research is acknowledged by the researchers e.g. (Tanner 2014)

2. Research on the emergence of a Complex Product System industry. Previous research and theory building on emerging industries has tended to focus on mass-manufacturing industries as opposed to complex product system (identified in Peltoniemi 2011). This research addresses this acknowledged gap.

7.5 Contribution to Knowledge

The research embodied in this thesis builds an understanding of the emergence of industry, for the particular case of a complex product system industry.

The following table sets out the contributions where this research either extends existing knowledge of the phenomenon of industry emergence or brings new knowledge to the topic.

Table 7.1 Contributions from this research

Section	Contribution
5.1	The documenting of an industry during emergence is a new contribution to the knowledge base.
5.1	The findings around legitimacy as a driver for industry emergence are congruent with existing literature, but suggest that the interaction in a specific industry is more complex. There is a causal loop feedback effect where legitimacy supports growth and successful growth boosts legitimacy. This is a new contribution to the topic.
5.1	This research provides new knowledge on the role of dominant design in a complex product system industry. This does not necessarily contradict previous knowledge (a dominant design exists) but shows that the role of dominant design is different in CoPS industry (no alternatives were pursued).
5.1	The finding on the nature of innovation is contrary to existing literature for mass manufacture industries. Further research with other complex product industries is required to identify whether this a feature only of offshore wind power.

7.6 Beneficiaries

There are a number of individuals and groups, industrial and academic, who can benefit from this research.

It is of use to policy setters and policy implementers who are working with new and emergent technologies and industries. The research highlights that there are actions that support the emergence of an industry (e.g. through building legitimacy, reducing risk etc.) that can have a detrimental effect on the long term viability of an industry (less able to respond to external shock, lack of industry cohesion).

The framework that results from this research is of value to the entrepreneurs and intrapreneurs who are engaging on exploiting a discontinuity (technical or market) that they have identified. They can use the framework to guide their strategic actions during the emergence stage of the industry e.g. building common purpose with would be competitors, identifying necessary areas for collaboration, formulating their interaction with institutions).

This research is of use to government institutions such as development agencies who can make use of the framework to guide their interactions with firms and to identify a number of particular roles that such institutions are well placed to fill:

- Critical friend / non-exec to the ‘industry board’
- Pull together ‘over competitive’ industry to share R&D
- Risk reduce (technology)

Finally, this research provides a basis for a new way of looking at ‘industry as a whole’ from an academic perspective. In this it is following trends in considering industry ecosystems to a logical conclusion that opens up a host of proven tools and techniques that can be applied in many more cases than simple emergence.

7.7 Limitations

This study has looked at a single case of an emerging industry. The rationale for this is discussed in depth in Chapter 2. It can be summarised by as a combination of factors;

- The research gap in observing industries emergence in ‘real time’
- The difficulty in knowing which industries will emerge
- The resource requirement for observing even a single industry

This research design does however bring a number of limitations and these are discussed below.

7.7.1 Methodological limitations

Sample size

There are significant limitations to the conclusions that can be drawn from the findings in the study of any single case. While this limitation was enforced by the nature of the topic (emerging industries are a rare phenomenon), it is acknowledged here that the proposed framework for interaction must be taken as a start point for further research (see section below) rather than a complete guide.

Reliability of data

With the imposition of a single case in a research design, the triangulation of data between self-reporting data, industry statistics and published data is an important tool for study reliability. In the analysis of industry statistics it became clear that different sources had different data for the same project (dates in particular). While the discrepancy is of concern, it may be expected where large volumes of data are being updated. The analysis of this data is concerned with averages and trends over the 50 live projects and so the impact of a single data point are reduced.

For consistency a single source of the data was used (BEIS, 2018). If there was a clear data error e.g. project construction start and end dates were the same, confirmation data was sought from project developers' websites. If data could not be confirmed the data point would be excluded – although this did not need to happen.

Lack of prior research studies on the topic

While there have been a number of case studies looking at the emergence of industry, none have investigated the emergence in 'real time'. This was acknowledged to be a risky endeavour as the impact of learning would be diminished by non-emergence, although this did not transpire.

The lack of prior studies of this type dictated a more grounded approach to the study that required a balance more towards breadth across the industry than depth. In retrospect, a focus on the developer organisations may have yielded more insights into the industry behaviour overall.

Measures used to collect the data

One of the inevitable limitations of a grounded study is that in late stages of the study, it becomes clear that alternative / additional data collection would have been beneficial. In this study it became clear when analysing the semi-structured interviews, and relating them to the annual conference mood, that the gut feel participants had about the industry was an important part of the picture.

Capturing short interviews about this at each of the annual conferences would have allowed more integration of this aspect with the objective data on industry activity.

Self-reported data

It is understood that self-reported data can contain several potential sources of bias that the researcher needs to be aware of. In this research the impressions that interviewees have about the success or otherwise of the industry plays a part in the analysis. It is clear that people remember things the relative importance of factors differently later. A clear example is that at the end of the study the general view was financing wasn’t a problem. This contradicted the notes taken at the time of the early conferences (2011-2014) when financing was a highly visible topic.

As discussed above, more longitudinal data on this feature would have been interesting. The limitation is not critically damaging however, as there is measurable output to show how financing has matured over the life of the study.

7.7.2 Researcher limitations

As well as the limitations inherent in the research design there are a number of limitations related to the researcher. These are discussed here.

Access

The researcher was very fortunate in being able to gain semi-structured interviews with individuals who had significant roles within the industry as it developed. However it must be recognised that this represented a small sample of all the those actively involved and could argued as representing the ‘promoters’ of the industry.

The analysis of views across the interview cohort is highly congruent which helps re-assure over the limitations of self-reported data, however more access to organisations who did not have as positive a view of it may have given more nuance to the analysis.

Longitudinal effects

Given the duration of this study (start 2011 – end 2018) it is important to address longitudinal effects on this study. It has been highly beneficial to have a multi-year perspective on how the industry sees itself through the annual conference. It has also been important to have a study duration that matches the development timescales of the projects.

The selection of when to stop the data collection has been imposed by university research timescales as much as by industry activity. While the achievement of the industry goal of <£100/MWh strike price is appropriate, it could equally be argued that extending the study to the point of zero-subsidy operation would be beneficial.

Cultural and other type of bias

Bias in this study is addressed through triangulation of 3 datasets (self-reporting data, industry statistics and published data). There is still scope for bias in the interpretation of the findings e.g. an inherent bias to the belief that it is possible to take positive actions to enhance industry emergence and viability.

The discussion of findings aims to draw out any bias by considering alternative propositions for the findings and explaining the choices this researcher has made.

7.8 Further Research

The on-going drive (both governmental and public) for a reduced or zero-carbon economy will see development of new energy sectors (energy storage, tidal stream generation) and potentially new industries (transport as a service being one). These are significant opportunities to build upon this research. A number of specific opportunities are suggested.

- Action-research on emergent industry: The framework presented can be used to work within an industry promoting organisation to enhance the emergence and viability of a new industry. The framework is developed from CoPS industry and could be applied to one of the potential emerging low carbon industries (e.g. tidal stream).
- Additional Emerging Industry Cases: This research demonstrates there is a need to build a knowledge base of cases of emerging industry. This will benefit both the study of industry as a system (whole) and the more single discipline focussed research using post hoc analysis. The research design used here could provide a template for such studies.

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Appendix 1: Collated Transcripts

Initial Interviews

<u>Andy Macdonald: 7 Jan 2011</u>

Role: Senior Director, Renewable Energy & Low Carbon Technologies, Scottish Enterprise

His view of the supply chain opportunity.

It is a significant inward investment opportunity, particularly for turbine manufacturers and the assembly operations.

One of the drivers will be the availability innovative:

- Infrastructure (including planning system and funding support)
- Supply chain (beyond tier one – taken as steel works, balance of plant etc.)
- Investment – needs investors who have the 'right' view
- Structures to support innovation activity

There is a role for conferences to promote interest in the opportunity.

What is the innovation 'space'?

There is lots of opportunity within the underpinning technology (blades, gearboxes, generators, transformers, distribution etc.). there is also opportunity for innovation in the services that are part of the development phase e.g. surveys, modelling.

The grid and its use could also benefit from innovative thinking (access charges aren't designed for renewable energy).

The potential looks to be there for reducing investment cost by 30% and by being 30% more efficient (load factor) than onshore.

Perceptions of industry 'today'

Oil and Gas skills and renewables don't 'fit'. This is mainly a perception – not anything hard and fast – but they come at things very differently.

This may change if there is a move towards 'Offshore Energy' as the focus of the joint activity.

What concerns for the industry (in Scotland)?

The site opportunities are easier in the south of the UK. The waters are shallower and the seabed is sandy giving easier operations for installation.

Technical concerns include the reliability of major components (gear systems, generators, hub bearings etc.)

There is potential capacity to do this, but it is not currently operating in the industry – people are awaiting 'volume' work.

There is an expectation of the transfer of expertise from oil and gas – doing OK but it is not smooth.

What next?:

Scottish enterprise is developing a database of companies who can be involved.

There will be a map of the supply chain.

Actively looking at Asian inward investment groups.

Expect it to be 2014 / 15 before real volume seen.

<u>Willie Dawson (3Sun): 16 Feb 2011</u>

Role: Owner / Manager of Dawson energy – just sold to 3Sun Ltd

Business:

The business is a supplier of specialist installation and operations & maintenance services to both the onshore and offshore wind power industries.

It started out initially providing services to fish farming and then, after 10 years, got involved with Onshore wind (via hydro-electric power) before getting involved in Offshore wind power.

The manpower tends to work on PAYE for the duration of contracts. Dawson has 90 employees at the time of the interview.

The employees are time-served fitters, electricians etc. but will require additional training before working offshore – typically 25 days. It could be an investment of £10-12k before the business is in a position to charge for people's time.

Most of the CVs (new applicants) are coming from Oil & Gas. Common ground is they are industries where you work away rather than specific skills (e.g. electrical, mechanical, instrumentation fitters).

The primary goal is to get into Ops and Maint work for Offshore (as a mirror to Onshore) but mostly the offshore work is installation (at the time of the interview).

Onshore work also includes retrofits. Where this is a whole site it is very like installation work.

The latest machinery (onshore) involves remote monitoring and control – they text direct to the technician if site support is required. Sometime work (resets) can be done remotely

Transfer to offshore:

By and large the turbines are the same, so the work (skills required) is the same. The main difference is the living conditions and the transfer to the turbine.

Transition pieces leave very confined access to the turbine. Transferring on boats can mean that half the shift goes sitting in an immersion suit on a small boat. The result is more work is being done from 'floatels' (hotel ships). This is an odd environment to live in – a bit prison like.

Offshore work patterns are more like oils and gas – e.g. 2 weeks on / 1 week off – whereas onshore it's often paid by the hour.

Weather has a huge impact on downtime → 70% on GG. Who pays for the cost overrun? These are very contractual based discussions. Contracts for the construction tend to be with the turbine manufacturers (Siemens, Vestas etc.)

As construction moves further offshore there will be more downtime. *(who is working to make the unique offshore stuff cheaper to do? e.g. crew transfers)*

There will be economies of scale with the O&M work – from parts supply to the ability to hold a tech on call.

The turbine producers provide the risk assessments and methods statements for the work. This means they are all different so technicians have to be trained for each one. There is a great opportunity to cost reduce through standardisation but who will drive this.

The industry is just beginning to get to grips with competency measurement and pre-tender requirements. This is comparable to FPAL (oil and gas) and Achilles (onshore wind) but different.

<u>Ken Moran (Wood Group) 7 Mar 2011</u>

Role: Head of Offshore Wind for Wood Group

How did you (your organisation) get involved with offshore wind power?

Wood Group are the ‘Duty Holders’ for Beatrice (*where 2off 5MW deep water demonstrators are sited – linked to the oil production platform)*

The company has been involved in a number of early offshore renewables projects including wave (Wood Group Australia and JP Kenney – a subsidiary)

The group is involved a bit with onshore operations and maintenance due to its Gas Turbine divisions electricity generator experience. Onshore work is very ‘mom & pop’ business where Wood Group needs scale (and scope) to compete.

Current involvement?

(At the time of interview) The group has all the skills necessary within it (e.g. JP Kenney for renewables; GTS for turbine generators, Engineering for offshore construction) and the renewables group is able to present this as a ‘shop front’ - a ‘blade tip to beach’ offering.

However there is a real need to ‘get going’ to put depth behind the offering and using shared resource is hard. The company has involvement in one test site (Beatrice) and one Round One site (Greater Gabbard).

Challenges (technical & other)?

There are some significant technical challenges in the basics such as access to the turbines offshore and the whole logistics & supply chain for doing the work.

There is a lot that is still know to be unknown which makes the business nervous.

An example is management of oil spills offshore. The international regulations are written for oil and gas. It doesn’t matter if its Deep Water Horizon in the Gulf of Mexico or an oil can slipping off the turbine – same protocols apply at this stage.

The wind turbine operating (H&S) rules are written for onshore – this is not the same environment as offshore, so there is confusion.

Collaboration opportunities?

There is a vision of shared resources to accelerate adoption / surveying / construction but it is hard to see how this will happen.

There is a logic for a standard contracting environment for the offshore work e.g. standard terms and conditions. This works in oil and gas e.g. knock for knock if vessel collides with platform. This is needed otherwise the cost of vessel indemnity would sink the company.

Also – can't operate with onshore risk models. The weather has too big (and growing) an impact on schedule and operating cost risk.

A big difference to Oil and Gas is that with oil if you loose time and don't pump – the oil is still there. With wind power, the site is only available for a fixed term – lost time is income lost forever.

Future?

There is a lack of clarity over what happens at the end of project life. There is an expectation of repowering but no clarity on how this will happen. Has a huge impact on infrastructure financial analysis.

Addendum

Ken Moran left Wood Group to join the offshore developer Dong, and then started a business with a colleague to provide services around vessels to the installation industry. This business is now thriving, but services the oil and gas sector rather than the offshore wind industry.

In follow up conversations with Ken, it was clear that the lack of activity in the installation industry made the switch to oil and gas critical for the fledgling company.

Alan MacAskill (Sea Energy Renewables) 14 July 2011

Role: Director SeaEnergy Renewables

Business:

Offshore Wind Power developer, currently working on developing a Round 3 lease site close to the original Beatrice demonstrator.

Background:

AM was an oil and gas developer who was involved in the Talisman group which developed the Beatrice oil and gas site and subsequently the Beatrice 10MW deep water demonstrator.

Alan doesn't believe that Renewables will (or even could) replace Oil and Gas as a sectoral employer. There is good business that should be of interest to O&G firms but the questions of – what, where, when are not easily answered.

Current Activity:

Sea Energy is working on a Round 3 site that represents a third of all the Scottish offshore wind developments.

There is a big disconnect between the government goals and the industry regarding scale and timelines for development:

- Financing
- Engineering input
- Shape of the developments
    - Slower development (2GW per year not 5+ GW)
    - Give visibility of on-going work (not boom & bust)
    - Time to learn
    - Time to apply learning

Finance:

In 2010 the business spent ~ £30M

In 2013 – 2015 will need to spend £100M per year

When construction gets underway spend increases by an order of magnitude.

Need to make a decision on the vessels to support construction (2016 – on) in 2012.

Early issues:

Health and Safety – we have to do this well (or someone will come and do it to us!). It will have to be compatible with Oil & gas activity (NB early sites, Round 1, have had fatalities during construction during load out on land – not a good measure for volume offshore work).

Contractual systems – have to recognise mutual risk

Renewables 101:

- Who is involved? SSE, Scottish Power, Vattenfall, Statoil, Centrica, RWE, Dong, Enerco
- Who isn't? EdF (not interested), Eon (failed)
- So far: 19 sites, developers forum run by the Energy Minister
- Round I – SSE view is book power near to the market. Not always the best wind resource, so not the best investment?
- Round II – go for sites anywhere you want; Irish Sea, the Wash, Thames Estuary
- STW – Scotland missed out on Round II (see SSE view of close to market)
- Round III – 9 zones defined by Crown Estate. (Was originally 10 but one zone failed planning already). Bids are to a target capacity
- Now have 48GW leased. Expect 10-12GW to fail during the planning stage. Strategic Environmental Assessments by March 2012.
- Timelines: Do we have the capacity / capability to develop all of the projects at the same time? Round I consenting took from 2 to 5 years after lease
- Installed Cost: (a big focus)
    - Technology areas: Bigger turbine, better substructure, better installation methods
    - Productivity areas: supply chain competition, serial production (NOT mass production)
    - Structure options (fatigue driven, not strength): Turbine; Depth; Soil conditions; Environmentals (sea state, wind, etc.)
    - Third reduction on installed cost is 'visible' now – but it must be done without cutting profitability (return for risk). Contractors will get the job if they are proven to meet the right cost model for everyone (under-bidding will fail too). Build on the Alliance concept for constructors / operators.

<u>Peter Hughs, Scottish Engineering / George Kennedy, Castle Precision 30 April 2012</u>

This was a brief conversation with Dr Peter Hughs (chair of Scottish Engineering) and George Kennedy Sales Manager at Castle Precision – a well respected precision engineering firm providing components to the aerospace industry.

The nature of the conversation was to gain non-involved (but technically literate and informed) personnels’ views and understanding of offshore wind power.

Both Dr Hughs and Mr Kennedy held the view that wind power would NEVER be the answer to the countries electrical energy needs. More than this, the pair suggested that support for wind power was taking support away from nuclear power which was the ONLY answer to the need for low carbon electricity.

When asked about what they new about the general technology and capabilities of wind power neither was clear on basic details such as cut in wind speed, cut out wind speed and nominal capacity of then current wind turbines.

The main feature they both discussed was that wind turbines would go on fire. (At the time of the conversation a local onshore wind farm had had a single turbine pitch control fail during a storm leading to the unit overheating and the gearbox oil going on fire.)

These views are a counter-point to the (naturally) positive views of those directly involved in the industry and serve as a reminder that the legitimacy of the industry needs to be proven.

- # Semi-Structured Interviews

‘A’ 26th Jan ‘17,

Background
What is your experience of OWP as an industry?

From a distance while involved with Scottish Renewables
At **XXX** more involved in Onshore, small site at Blyth is a learning opportunity before starting large scale wind farms offshore
Policy role involves all renewables and includes OWP views

How long have you been involved?

10 years ago (since 2007) – Scot Renewables
Aware during MSc at Dundee of 2 Beatrice turbines. These showed that deep water turbines (around 30m) are possible.

Financing OWP

Role of financing activity?

We have seen a big shift in the way projects are supported. Under ROCs the project has limited value until consent even though you are spending real money … But once you have consent then banks will understand the money will come.

Situation now (Under CfD) you get to consent and have to bid against all technologies. Outcome can go a number of ways:

- be too competitive and get the CfD, but it’s not enough for your project
- not competitive enough, no CfD and so no way of funding it

When a CfD is won, the finance may in fact be more straight forward than with a ROC. ROC had more risk in operation than a CfD

So the CfD process makes the go/no go decision quite far down the development cycle? Yeah

Any successes/failures about how financing worked?

Not really close enough to this.
But if you look at projects they are coming from large utilities who have clout (with bank, or on balance sheet)

Innovation

How do you see innovation activity / how well has it happened?

Obvious innovation is the large size of wtgs
Now moving into deeper waters and don’t know how that will work:

* bigger jackets
* different development (of jacket)
* more hostile environment

Needed innovations are still to be proven? Exactly

Electrical connection included – has to be better than current tech due to environment. Maybe HVDC. First test on Shetland connector?

Any failures of the innovation activity?

Any failures are not around will, or technical capability but thru' circumstances e.g. Aberdeen bay project. Value would be greater if it happened earlier.

Change of funding mechanism has reduced the cooperation – impacts innovation. People won't know what the real LCOE is for CfD projects.

Supply base is now where innovation flows.

BUT Oil & Gas attitude of no-one wants to be first with a supplier's technology.

Planning regime

How has this worked for OWP?

The crown estates leasing processes was just lines on paper. No real basis of suitability as a wind farm site (what is there, what are sea bed conditions, what lives there etc) c.f. onshore – it's a bog! it's a city!

Impact is Judicial Review of Firth of Forth windfarms, Navitus Bay world heritage site, busiest shipping channel in the world ..

Elements like that. In Denmark / Germany sites are being offered as fully developed sites / all you have to do is build and operate. Getting very low bids for cost of energy as a result – greatly reduced development risk.

Energy market

Thoughts on that?

Overall a good thing, brings in competition, makes people thank about what they are building (costs and how well they can do it), true across all technologies – where can we be more efficient, we have to be more efficient

Energy Market Review was not just CfD also Carbon Price floor (so must include in cost of generation), emissions, (others)

Things that went wrong:

- Didn’t match the budget with the aspirations – the money is already spent before 2020
- Did the government use the right methodology – the wholesale price has been very low so support money is used quickly. May be better to look at the retail price to consumers. More transparent then
- Made assumptions about load factors that were too low. Maybe could have bid both LCOE and the total MWh output per year

End result renewables support has run out. Trying to bring all technologies together...

Is OWP successful?

Yes! Specifically managed to get a manufacturing base set-up (Siemens Hull) which onshore hasn’t.

UK is the leader in OWP (*true*?)

What challenges has it faced successfully?

Manufacturing base
Regulatory regime around transmission.

What challenges could have been more effectively addressed?

Site leasing without more detail on site (see above)

What future challenges?

Cost → subsidy free
Technologies → convince developers it will be there to support cost

Industry leader?

UK as a country is bandied about

(East Anglia 1 ?) Scottish Power / Iberdrola

Structure of the Industry?

<Slow to answer>
Interesting question just to see how it would be answered
Compare to Nuclear – many specific elements for that industry e.g. World Association of Nuclear Operators (WANO)
Structure is free-form at the moment.

Ideal Wind farm?

No – not yet, too much to discover

Will OWP survive longer term?

Yes – it is about life cycle. New technology may go for repowering early. Things will wear out.
Expect Mid 2030s it may be about repowering

Is there a better place to do this?

No idea!
A lot of factors in there …

What have I missed?

The industry has been unrealistic about timescales … lack of manpower / knowledge etc.
Very different to other manufacturing / product industries
Assets have a long life so need to be risk adverse

‘B’ 6th Feb ‘17,

Background

What is your experience of OWP as an industry?

Involved in technology for 7 years (at time of interview)
ROLE Scottish Governments aspirations to maximise the opportunity for environmental and economic benefit to Scotland
Various tools to achieve that
Work closely with public sector and industry players

Financing OWP

Role of financing activity?
Majority of financing is around the subsidy – otherwise no developers would be involved
ROC – get your consent and build as much as you possibly can
CfD – competitive option process. Even if you have the planning consent it’s not guaranteed
Lower subsidy now 15 years, lower rate of return.

Early sessions on financing said finance must be off balance sheet (so expensive).

Early funding is on balance sheet. Getting consent removes a big risk so can attract finance.

The project finance is complicated. Lots changes as the project progresses. Beatrice given as an example. Developers and utilities want to recycle their funds (once there is a clear line of site to revenue) to the next project.

Has changed a great deal as move from ROC to CfD – in terms of stage people come in.

Innovation

How do you see innovation activity / how well has it happened?

A bit clunky at the start – onshore turbine with a life-jacket on it
A big acceleration in the last 4 years of size of turbines from 2 – 3 MW (round 1/2) to 8 MW (round 3)
Driven by experience and drive further offshore
Foundation technologies progressed (mono-pile, jacket, floating)

Planning regime

How has this worked for OWP?

Early rounds were done in a way that sites were just plonked down – knowing what we know now would have chosen different sites.

Government (through Marine Scotland) is looking to have process that identifies much 'better' sites.
Started very early without really knowing what the technologies were (there is a boot strap element here)
Knowledge from rounds 1 & 2 is being fed into better round 3 and further round the world

Companies will go where the market is. There is no 'loyalty'. UK has made it that a lot of money is invested before the win. Other countries have lower barriers (e'g Denmark and its well defined sites). Potentially this will lead to boards saying do develop in UK.

Energy market

Thoughts on that?
(2020 target is challenging due to delays from moving ROC to CfD and onshore having no route to market)
Targets help show how committed the Government is, regardless of mechanisms.
Need a stable market cf Trump
we do need stability – what's coming (hence 2030 targets)

Underlying assumption is margins will be squeezed
Delivery milestones mean projects have to crack on and deliver before the CfD lapses (no contingencies on time and budget).

CfD rounds are not clear now. Nov 16 - will be 3. only one by Feb 17. No idea when the next will be. What are are they going to do with the remaining pot …

Transparency is needed to get supply chain and developers to invest. There are investors out there.

Is OWP successful?

It is mirroring onshore success. It has evolved similarly as an energy producer
Needs to be part of an energy mix
Has been dependent on the need of the government

What challenges has it faced successfully?

Has become a credible energy producer
Surprised people how quickly it has evolved

What challenges could have been more effectively addressed?

Not asked

What future challenges?

Further offshore
Become global
Energy storage / broader energy mix

Demand growth – maintain / boot strap
Interconnection (high pressure still air in one place are balanced by a gale in another)

Industry leader?

Dong – the biggest developer player UK / Japan ? / States
Siemens for WTG

Structure of the Industry?

Aspects – everyone needs to play a part.

Government / Developers / Grid / Financial need all the players come together to make it happen. For some they aren't enthusiasts

No other sub-systems but fractal nature is relevant. All interact

External factors (e.g. Brexit) also. In fact amount of change in the life of a project is significant in all PESTEL factors

Discussion about the linkage to Oil & Gas at the individual skills / people level.

Ideal Wind farm?

No – still lots of work on the basic science (wake effects), what's the layout etc.

Will OWP survive longer term?

It will survive pushing on at pace to end of 2020's
If it doesn't it is because there is something better.
Government appetite, public acceptability, consumer impact (cost) all support this

Is there a better place to do this?

France happy to flout EU support laws
Chinese setting up to flood market SDIC

What have I missed?

Incoming big players may move things

‘C’ 30th March 17,

Background

What is your experience of OWP as an industry?

Started in policy in **XXXX** – other teams doing the development.
Deeply involved in machinations over what it would take to make an industry
Roles in the trade associations Scottish Renewables, Renewables UK
(**ROLE**) Cost reduction panel for Energy Minister 5/6 years before. Golden target of £100/Mwhr LCOE (£140 or higher)
Deeply involved across the industry.

What does it take to create an industry?
Just talking to the senior guys interested in the industry (developers and tech). Look at barriers to getting full potential. Wasn’t the technology. Issues were scale and delay around the processes that put the projects together.

Could see this was eminently doable – nothing had to be really invented to get cost down. Collegiate willingness across all the industry that if we did pull together we could actually achieve all this stuff – working closely with government, working across the supply chain

Financing OWP

Role of financing activity?
Financing has been critical. The difference between offshore and onshore is the scale of projects, far less smaller independent players in offshore. One of the factors for the proliferation of (onshore) wind was it was not just dependent on the large utilities. There were all these small developers taking on projects otherwise seen to be too difficult or small.

The challenge for offshore how does it grow when fewer big players and more expensive projects. Onshore, projects can be done on balance sheet, if a project fails its no big deal. Offshore the project can risk the whole company.

So different types of investors. Its a fledgling growing thing. Early on there are investors willing to take the construction period risk, as the the project develops it’s flipped to the more pension fund style investors.

Was a major worry, but not come out short. Still see the two types of investor and the constant refinancing element. I think it adds some expense to the efficiency of the market.

Is the financing pattern unique to OWP?

I don’t know if it is unique, but OWP has its own special qualities. Particularly as pertains to planning delays. This is in contrast to Oil & Gas – it has less schedule risk.

Innovation

How do you see innovation activity / how well has it happened?

It’s a tricky thing because we’ve grown up in a privatised market from the late 80’s. Prior to privatisation the industry used to spend a lot on R&D – this stopped ‘overnight’. Since then there was 20 years of ‘we just buy mature products’. Gave a cultural barrier – innovation = risk = more cost.

XXXX is saying actually innovation is about taking risks out, its about doing things better – learning things, get what works take cost out of the next project. Its not about INVENTION of new products it’s innovation.

The biggest innovation have come from the developer / owners working with the supply chain (mainly the WTG producers) to up scale the machines 3 – 7/8 plus. Huge impact to the p/kwh. Give the manufacturers the visibility of the next projects to build the factories, get momentum, allow things to flow as opposed to stop-start stop-start wait 5 years.
That’s not how you build an industry.

When you keep things in motion that gives people confidence and allows them to invest for a long term future.

Innovation to date mainly in the turbines. Industry now has the confidence that politically it can justify itself (costs down). Getting to the stage like automotive and aerospace where although arguably cheap, can afford to invest in new innovation. End to end (broader scope)
3 blade dominant design ‘works’ so why change while proving cost / volume?

Planning regime

How has this worked for OWP?

A lot is the lack of ‘true knowledge’ of what is there early on. Don’t knows what’s out there and what needs protected.

Because of the lack, the precautionary principle has thrown the load to the developers. Prove there is no problem (logically hard). NB Oil & Gas is not subject to the same regime.

Marine Scotland – did that work?
No – it didn’t

Energy market

Thoughts on that?
Was against the introduction of CfD. Done mainly as a nuclear thing (just to show not giving subsidy to nuclear). Also onshore small developers saw ROC as an uplift to wholesale price – they didn’t have the wherewithall to predict future wholesale price so this was a risk – they went to utility to get a PPA but that would be heavily discounted. Some FIT like system will take away wholesale risk. CfD was just a mechanism to move the risk around and would have as many (but new) problems.

Biggest problem with CfDs has been the budget around CfD – it isn't big enough to enable all the early projects already under development. Spend 10s £M or even 100s £M over 5 years to find can't get consent or can't get CfD. Who wants to work in that market … only the brave.
CfD may have helped a bit, but very early introduction of competition may have been a bit of a stumbling block for the industry.

Has it changed how the industry works together?
Big issue for **XXXX** – with CfD trying to compete for limited pool of CfD industry does not collaborate to resolve technical issues.

Has it impacted supply chain?
Big boys looking for exclusive rights to the supply chain capacity

An aside about competition
Lack of competition is a danger for any market. (People were saying a few years ago) let's just accept there will be 2 big players in turbines and in supply chain… not good going forward. See Vestas – too big for own good.

When I talk to a lot of industry big players they don't like it (dominant position) because they get blamed for the ills of the whole industry.

Is OWP successful?

What challenges has it faced successfully?
Cost out

Developers are not supply chain experts (utilities). Now doing better at this for local content in CfD proposals. And getting positive feedback from this. (They like the responsiveness. How can we make this for UK industry?). Massive political pressure here.

Communication and understanding with supply chain.

What challenges could have been more effectively addressed?
Bring O&M experience into design

Planning processes – e.g. sharing of data for planning (and the Danes & Dutch approach. Takes cost AND risk out)

Do it the Dutch way to accelerate the projects (and involve the supply chain)

What future challenges?

- Some technology examples – further / deeper implies floating wind turbines
- Do the sites need to be developed by utilities?
- Foundations challenges
- Financing / types of developers
- Grid connection – point to point. When grid? When DC? Different AC tech?
- This side of thing is the impact of a bunch of projects as opposed to a cohesive industry.

Industry leader?

Developers – Dong / Scottish Power
WTG – Siemens / MHI Vestas

Structure of the Industry?

Any aspects might be described differently

Behaves as a bunch of projects
Ops & Maintenance – you must feed that experience into next projects. Not happening yet in OWP despite it being the SAME people.
Capex is so big compared to O&M focus is there. Beginning to realise need to close the cycle between O&M and design.

Ideal Wind farm?

n/a

Will OWP survive longer term?

Don't see it coming to a full stop. Can look to a no CfD future and the scale depends on consumer appetite (which may be much more)
IoT will change the nature dramatically e.g. planning processes / data
There are other barriers ports / floating hotels / grid system (designed in 1920's for 5 big generation points)

Is there a better place to do this?

n/a

What have I missed? n/a

'D' - 17th May 17

D aside:
Results of German and Dutch (Danish) tenders Danish prices in 50s Germans 50s – 60s. But not necessary the same as UK. The Danish doesn't include the development costs and the German price doesn't include grid connection.

Danish model works as it is a small country. It would be too complex in the UK as a whole (relevant for an independent Scotland?). Real question is - 'Is government capable of doing it?'. Also is the government conflicted – consenter and statutory authority.

German have bid prices that are non-subsidised. Based on the assumption by Dong that they will have 13 – 15MW turbines by the time it goes to construction.

Germans have a model where the grid comes to them – one upon a time (pre-privatisation) this was true for fossil fuel and nuclear.

Background

One of the pioneers – deepest installed and furthest offshore. Started involvement 2001

Started as an Oil company developing OWP.

Emphasising 'aspects' of the industry.
Larger projects needed financing

When offshore came in over the ROC – everyone said how terrible it was compared to what was before. When they changed to CfD everyone said how terrible it was compared to ROC. The fact is as long as you are accepting a subsidy, the government is going to set the rules and change the rules.

The issue is the length of time it takes financing people to get comfortable. Beatrice happened very quickly as we did it as an oil company – we (oil) don't finance projects individually – the balance sheet could afford it and it was a small project. We just went and did it collecting a few grants along the way. Got the costs wrong along the way £9 – £17M (£30M overall to £45M).

Time taking to get financing comfortable

Contrast to oil company projects where developing a depleting resource – have to balance everything over the whole corporation. People lend to the whole company not an individual project.

OWP has a clearer income stream once running for 25 years (NB 15 year CfD) and fairly flat (depending on wind speed).

Round 1 was on balance sheet. Not very big and no-one with experience to fund.

Once it got going (round 2) then it was possible to move off balance sheet.

Current company has a different philosophy. Do the development (including prototype foundations – floating) on balance sheet then sell the whole project). Well understood risk.

Innovation

Has worked well! Came in as an arrogant oil man. It is a technically advanced industry – but in a different way to oil. It is not bespoke tech it is serialised (but not mass-manufacture).
At the start was told (by a prof) you can't build a WTG bigger than 3MW. There will be 15MW, but there could be 20MW (very different foundation tech).

Transference to floating changes the problems – the civil engineering challenge of raising a 125M tall tower. Floating changes things – jack it up, do the hard stuff onshore.

Innovation has to be possible stepwise. Example - opportunity for concrete foundations didn't happen because it needed scale in one go. Any economy of scale comes from large projects rather than across projects.

Dong has a stream of projects but the economy of scale comes serially, one project then another.

Compare FPSO and Floating turbines… greatly reduces the capex for a project. The sub-structure could be financed like a ship.

Planning

The planning regime for OWP can be split into 2 camps, the incompetent and the competent.

Incompetent: Marine Scotland. They can't do anything in the time-frame they promise, and then they don't get it right.

Competent: The English system works quite effectively. No-one is saying it's rapid but it is effective.

The Scottish system is appalling it's badly run and managed.

Has it impacted particularly on the industry in Scotland? Yes.

You have to look at what makes this industry difficult to consent. I think there are 2 things
1. Don't piss people off. The best way to piss people off is to let them see it. If you can move away from there you reduce the complexity by an order of magnitude

2. Manage the environmental lobby effectively. In many ways this is the same impact.

Floating gives a bigger sweet spot – 50km (over the horizon), within an AC connection of the land range

If you change the regime so that the grid is paid for (like motorways) then you can site for best resource. The country then sets up 'inter-generational' assets like the grid (expensive but lasts a long long time 50years to 100years)

Impact of bending where you build the capacity to suit the grid seems wrong. End up with the wrong optimisation.

Not a right answer (*but many wrong answers?*)

The 2 extremes are - build where best resource and then get it to market OR build close to the best market and find an ok resource.

Energy market Reform

Loads of money for professional services.

The end is as long it creates a funding system that lets people make a return then you can live with it.

The industry will cease to need subsidy, certainly no more than fossil fuels.

Has it changed the ways projects are configured?

I don't really know. I'm an engineering / developer.

I don't give a damn about the LCOE, I don't know what it is. I just want to see that I can develop the project to make a profitable income stream. Someone else can work it out.

LCOE has a big GIGO issue.

Look at the NPV and the rate of return of the project I'm dealing with at the time.

Asides
<long discussion about how to cost / value / make investment decisions>

<Projects sizes will be typically about 500MW – so 30 – 40 machines. £1B is easier to fund than £2B >

<Panels put out lots of well argued <u>opinions</u> about what is best. These are really only true from within a single company (Developer). Lots of different organisations out there so you get lots of different looking projects because people are valuing different things. (Worth looking at SpaceX approach to launcher market?)>

Other Aspects – incoming call interrupted

This is an infrastructure business – it will go in cycles, good times and bad times. Things will happen, industry will react and things will change again.

<Use floating wind as an example. Popularity was low, **XXXX** ploughs on, now more interest and there will be a glut. Things will fall back to a higher base, then pick up if it is right.>

Phases: Demonstration, pilot, pre-commercial (reasonable scale but not yet cost-competitive), (after 1 or 2 projects) hey we got this and real commercial scale will happen. Until something else comes along …

Some of the factors are real, some of it is sentiment. If you are working in any large capital investment industry it is very susceptible to cycles.

Is offshore wind power a successful industry?

Reasonably successful. Will be subsidy free middle of next decade for certain technology. It will become a different industry. When there is no subsidy required people will build on the assumption of a higher price. The building will lower the actual price so remove attractiveness. Someone will decide to build anyway and makes a killing as the price rises because others have left the market.

Future Challenges

For all renewables it's intermittency – it has to be solved. Anyway demand is intermittent and it can be dealt with.

Energy business needs to be better integrated between demand and supply. Demand can be massaged.

Industry leader

Dong stands out. It's not the best necessarily. They've managed to get things moving. But they are the big fish in the local pond. How will it work when they move to the far east.

Others are following along – RWE, Eon etc.

Ideal wind farm

The right one. Scale we've discussed (500MW …)

Anywhere better?

Lots of discussion of beneficial points.

Combine with other industries – offshore wind / fish farming / biomass (seaweed)

Talks about storage / ammonium etc.

‘E’ - 24th August 2017

Background

Project Manager for **XXX** project.

XXXX exclusivity 2009 – pick a site in Scotland. (STW round).
Joined at the start of 2010 (from oil & gas) at the point of grid connection. Joined as project engineer moving to essentially country manager, Scotland for OWP with the goal of wrapping up **XXX** and then developing a pipeline of projects for Scotland.

8.5 years later **XXX** is not finished (on the cusp of moving to financial close and construction stage) and no other opportunities. Nothing new has been offered since 2009.

<timeline of project is illuminating. Onshore consent BEFORE offshore – despite focus of Marine Scotland. Onshore consent came thru’ in a year with NO objections. Offshore consent took 27 months against government quoted target of 9 months. After consent (of 4 projects at once) RSPB went to Judicial Review.

After winning judicial review the project competed for CfD and won. As project stalled due to Force Majeur (RSPB appeal against JR outcome) LCC terminated the CfD contract (unlawfully). RSPB won their appeal against the Scottish ministers.

Ministers appealed and **XXX** went to arbitration against LCC (for terminating the CfD contract).

Both cases heard within 2 weeks of each other in 2017 both results favourable to NNG.>

Also health & safety for OWP

Financing

Commentry – timing for **XXX** was a long way down the road to Financial Close with the CfD. This gives a lot of certainty to investors. ROC (3 years earlier) was much

XXX was 75% debt 25% equity (heavily leveraged).

<comment on the ‘mood’ of conferences …>

* how much are we gonna build
* when are we gonna build it
* if we’re gonna build it
* don’t really know anymore – nothing is getting built
* We *might* get some of this built>

Currently very healthy. The next tranche of projects wonder how it will cope.

The CfD process after a certain point (in a project life cycle) is welcomed by everyone. However developers are less happy with the amount of expenditure to get to the option for CfD stage. Less enthusiasm for development greenfield sites. Currently huge appetite in the market for investment after this.

Interesting to see different organisations moving into and out of investment / ownership.

Innovation

It has worked amazingly. It has played a huge huge part in accelerating the industry. Don't know how much longer it can continue to do so. It was innovation with collaboration. CfD doesn't allow collaboration at development stage.

Still big opportunities in O&M.

Example of collaboration was Mainstream deploying a twisted jacket MetMast in Hornsea. Saved 20% of this budget line.

Acceleration of turbines – the project started with 125 x 3.6 MW; current revision is 54 x 8.4 MW; looking at 9.5MW and 15MW are over the horizon.

205m tip heights for **XXX**. Any later and they would be 250m. Plans in outline have 300m (1000ft!!) tip height.

Even close to the industry didn't plan for the rate of turbine growth. **XXX** will have half as many as original plan.

Rate of change of blade length is amazing. 100M blades don't fit the NEW yards.

Were we lacking ambition for OWP tech?

No we were lucky to get all the ducks lined up. A Swiss cheese accident of enthusiasm – policy alignment, government alignment, subsidy alignment, public alignment, industry wanting to set up and also downturn in oil and gas.

'The future is renewables' it created the ability to go *wooooffffffff*.

That was eroded and it was not sustainable with hindsight. We were looking 5 years ahead, now looking for 15 years ahead. Crown estate leases are not designed for these lengths of time.

Planning Regime

UK as a whole. With round 3 for Eng & Wales, getting the CfD was painful but it was a good solution.

The PINS process down south works.

Scotland hated CfD and hated PINS. But all the down south projects worked. Robust and transparent process so huge certainty. With Hornsea we were told it would be 18 months – and it was to the day.

In Scotland the process lacks bite so it is open to abuse from stakeholders. **XXX** was said to be 9 months, took 27 and then got further delayed 36 months through review. How **XXX** has survived the process is a miracle.

Scotland needs to adopt something like PINS.

<list of 4 licenses required in Scotland>

… some way to go …

Planning and CfD interlink.

Energy market Review
People didn't like it but CfDs worked

As soon as you've got one it is a wonderful thing. It is really painful to get there.

Outside, looking in, it is good for consumers to see that OWP is cost competitive with nuclear.

<aside – complementary sectors and what they are doing

How do you see the industry:
With Oil & Gas = marine energy
With Onshore = renewables>

<talk about spot pricing and negative prices => storage will make a huge change >

<NCP car parks as a storage power utility>

Offshore conversion to hydrogen or ammonium (not grid connected) Make fuels

Aspects not covered

Look at the closely related industries

Why I think OWP will be a success. Moved from Oil & Gas as renewables is a more ethical approach. Moving from nuclear, reducing gas, need security of supply. Money for developing IS flowing thru' Scotland so we get polcy / political alignment.

Has become / is becoming a no brainer. Investors / OEMs can believe it will be a long term market.

Can see the tangible support there, again builds confidence.

<Fraser of Allander report on economic value of **XXX**:

13,000 person year jobs>

OWP will go on unless something BETTER comes along.

OWP Successful?

Challenges met / not met / future

Almost there at proving itself as a global / go to solution for energy.

Challenge that can't do base like nuclear, can't do deployment like gas

Success in Scotland – NO. Too boom and bust. If Beatrice doesn't go ahead then the industry will just dissapate

Failed challenges
Hasn't managed to build a pipeline for Scotland

Success at a global and UK level but not Scotland (examples of what has stalled it) confirms the view that nascent industries go global instantly to addresss blockages. Marine tech actually helps this.

Leader in OWP

Hard to see past Dong. But being pressed by Vattenfall, Statoil.

Ideal OWP farm?

Ideal windfarm may not exist?

Shallow but not too shallow (cables install, vessel access).
Close to shore
Close to a load centre
High wind

It is an onshore windfarm on Shetland – 50% capacity factor. Install on the coastline.

Survive into the future

Already said yes – what will it look like?

Bigger certainly but hard to see 2 blade / downwind turbines etc. getting funded.

Maybe a change from cable to shore to refuelling electric ships …

O&M innovations to support

‘F’ - 18th October 2018

Background

Started at SCDI 2007-2009. Commissioned a piece of work to look at whether the Scottish Government target of 50% of electricity generated by renewables for 2020 was possible (sentiment said not).

Wood Mackenzie report – can we hit this target. Yes – expect to be 55%. May not have included offshore wind.

At the time of joining **XXXX** (Sept 2009) there was not a huge awareness of offshore wind in Scotland. Changed when Round 3 was announced – came out of left field and exploded.
Role to campaign for the optimal legislative, regulatory, financial framework for the growth of renewables in Scotland. OWP is one 4 to 5 key sectors.

ROC = renewables

Financing

Early days there were distinct models for independents who only do renewables (mainstream), integrated utilities who do all generation, plus transmission and retail (Scottish Power) who can fund off-balance sheet, start-up companies such as SeaEnergy (AmcA) – they were part financed by the disposal of oil & gas assets to fund early development stages.

How things have changed – assets being bought and sold at different stages of development. Groups like Copenhagen Infrastructure partners (part funded by pension funds).

Moved from business in OWP chasing finance, to people in finance looking for businesses to invest in. Become an infrastructure investment business.

Large companies raising finance through Green Bonds (set criteria). GIB not involved in Scotland.

Not been one model that has funded development.

Finance wasn’t an issue from the finance people’s view – just need good projects.

Innovation

My understanding it’s been driven by bigger turbines. Compare NNG with MORL

Also people just getting comfortable.

Has support for innovation been successful?

Must have been – tripled the size of production units in a decade.

Cost reduction – may be a false baseline in 2ROCs = £150 LCoE

Would the innovation have happened even without the support? Probably – best turbine at best price then you'll fight to be that. Doesn't hurt to have all that government 'stuff' around but my sense is *if you could run it all again* it would have happened anyway.

May be a bit harsh on the institutions. Started this before the catapult was in place. What maybe did help was the Cost Reduction Task Force - *i*t gave people a place to aim for.

To flip the question – has the move away from ROC to CfD (and even competition to get hands on a CfD) driven cost reduction? Absolutely. It has been transformative.

Planning Regime

For the projects I was around to see (STW and Round 3) the planning system was clearly not equipped to deal with the projects, because the planning system didn't really know HOW to deal with the projects.

They'd never had to deal with this type of project, so in designing a system they had to guess what may come up e.g. deemed consent – if you get an onshore consent you get an offshore one.

Took a lot longer than indicative timescales. The planning bureaucracy couldn't cope with the volumes of things in the timescales.

The NNG judicial review wasn't a surprise because of newness, but people did quite quickly flip back to say the review itself was flawed and actually the planning process was robust – and the positive decision should be upheld.

It was a challenge for developers – they always wanted the consent 'now'. They were perhaps unrealistic about the importance of a robust consent system – and if that took longer it took longer.

England v. Scotland. People judge the system on the result they got (if was what they wanted it was good, if they didn't it was bad) rather than the process – that is wrong.

Energy Market Review

Crown Estate were delighted with Round 3. ROC regime built up unrealistic expectations of what could be supported and what could be built.

It was always hard to argue against the logic of letting the market decide the price rather than setting it (via 2ROCs). Also the EU rules on state aid require a competitive process – this would have driven something even if UK hadn't decided to do it.

People were comfortable with it until they realised they might not get a contract … Then they were very uncomfortable. I believe projects would not have been developed as far as they were if people had understood that there would be an auction and some people would loose.

Most projects will have kicked off on the basis of ROC. Some developers became comfortable with CfD quickly, others had developments based on RO and felt they'd had something taken away from them.

My view was the change is irresistible – competition drives down prices.

Aspects not covered
The crown estates is a small organisation. They went for a massive round to try and generate scale quickly to drive down costs.

In hindsight I think that strategy didn't work. Made some people do some strange things e.g. Argyll Array (breeding ground for Basking Sharks). People scrambled to get sites so they wouldn't loose out. More frequent, smaller rounds would have worked better.

Discussion / description around unrealistic ideas that have led to disappointments in industry (number of turbine manufacturing sites etc.) including jobs …

There's was a lot of discussion of what would be needed based on intuitive feel, when NO-ONE had the experience to back it up.

One other thing to say as is … [within the industry body] there was a view 'it'll never happen, it's too expensive, too complex, we're not going to need it, lots of space onshore'. And it HAS happened.

Similarly … 'If it does happen it'll be in the southern North Sea, not in Scotland' - but there is significant investment in Scotland (Beatrice, MORL, so far...).

SEA should have been done first … oops (but we learned). It is understandable as it is actually quite a small number of people (circa 10) who went to do this. The government didn't see it coming.

OWP Successful?

Yes – in 2011 if you'd said by 2020 you'll have (Beatrice etc …) I'd have said WOW really!?

There was a self-reinforcing excitement and Crown Estate drove some of that – have to build by 2020.

Could we have captured more of the economic activity – yes. Better prep of the supply chain.

What would that have looked like?

Serial manufacture of turbines, or wind towers, or subsea jackets etc. The one bit we have (BiFab) can't compete due to lack of serial production equipment.

So, Yes in challenging conditions.

Leader in OWP

Allan MacAskill – Beatrice / KOWL / Seaenergy; Adrian Gillespie; Alex Salmond

‘If we have someone coming into talk about investment at the <port>, the delegation is met by the First Minister.’

If they go to England there met with a rep.

Scottish Power, Dong, Vestas

Jim McDonald, Andrew Jamieson

Ideal OWP farm?

No – bigger, floating, UK further afield

Store energy at turbine.

Lots of ways of increasing the value, and what is offers.

Survive into the future

15 years out …

Will people still be building wind turbines offshore in 2033. Yes seems too strong but yes.

Anything I’ve missed?

No

Global market for this and we’re just at the start.

Appendix 2: Notes from the Conferences

2011

Exhibition

- lots of computer generated images of equipment
- lots of services being offered
- lots of services / survey equipment

Keynote (Niall Stuart / Petrofac / Wood group)

- SEA ongoing - Scottish Renewables forum provided the industry input
- Involved in the ‘Spatial Plan’ for the North Sea
- About creating an Offshore **Energy** Sector – common purpose with oil and gas, not competition with …
- Competition is any country bordering the North Sea.
- Legislative impact on competition (with other energy sources) of Electricity Act
- Inward investment happening – Mitsubishi buying into hydraulic power in Edinburgh, Gamesa investing in Glasgow, Technip investing in Aberdeen (bought SubOcean assets for renewables)

Keynote (Alex Salmond)

- High business birthrate in Aberdeen
- *‘I believe this is due to Aberdeen being a decision centre for many firms’*
- Shrinking sectors lead to low growth, growing sectors lead to high growth
- ‘*We know more about our offshores than any country in the world’*. [What about Norway, Denmark, Germany?]

- There are licences for 12GW in place, 200 GW is technically possible and 60GW is foreseeable
- The economic margin on renewables is NOT like Oil & Gas
- There are political issues – money to community goes to the UK exchequer, there is the connection charge issue [Scottish sites pay a higher grid charge than English]
- There is opportunity in a super-grid of European Grids
- SSE will partner to generate an interconnect across the North Sea to Norway
    - ScotGov will pay for the survey
    - Link to Norwegian pump storage

Keynote (Keith Anderson)

- Greta opportunity for collaboration between Oil and Gas and Offshore Wind Power
- There is ‘certainty’ for the future
- BUT operating 1GW
    - Cost overruns
    - Safety issues
    - Delay
- OWP need O&G experience of operating at sea
- there is an opportunity for growth (not just replacement of O&G)
- Size of the prize in question
    - Blip and then gone?
    - Look at the 5 year opportunity
    - SPR has 9GW of projects, 25/30GW planned for 2025/30, £90B investment plan. Beyond 2025 another £25B
    - There will be an O&M industry for 20 years after 2025
- Call to arms to get involved.

- Look for Clarity & Certainty
    - We’re showing our investment intention
    - Energy market Review must be done **quickly**
    - EMR outcomes must be **good**

Keynote Paul Lewis (MD operations for Scottish Enterprise)

- Scottish Low Carbon Economic Strategy – to drive growth
- Oppy for £7.1B GVA to the Scottish economy
- Need to look at Bremerhaven Integrated Manufacturing Park
- Support to companies: Offshore wind expert Help programme, Offshore Wind Interest Group, National Renewables Infrastructure Plan (N-RIP)
- Exemplar: BiFab transform from O&G to OWP
- Lacking Turbine Manufacturer

Highlights:

- 2014 – 2017 cliff face (of projects ending before next start)
- UK leads world in OWP but EMR has brought to a standstill
- UK supply chain needs to get into Germany to survive the 2014 cliff face
- 90% of employment is in the contracting side. that’s where the knowledge will come from.

Key challenges:

Morag McCorkindale (AREG)

- Opportunity to stimulate the economy
- Need to work together within country (for success)
- Technical requirements (better kit, better install methods)
- Infrastructure (ports)
- Resource – skills, steel, finance

- Consenting

Ron Cookson (Technip)

- Challenge to O&G, extract the expereince but don’t loose the expertise
- The opportunity is TOO BIG to deliver
- Terms of engagement have to change to bring in the contractors
- Need to talk added value (not reduced cost) [Costs need to come down]

Alistair Birnie (Subsea UK chief executive)

- Demonstrate good use of capital
- 20% growth in Oil & Gas (hardly terminal decline)
- H&C is 3 tiems worse than it needs to be.

Arnaud Bouille (KPMG)

- Delivery – needs Oil and Gas expertise
- Innovation
  - Test sites with easy consent [Aberdeen Bay?]
  - Local R&D [Glasgow?]
- Access to capital
- Policy is a challenge

Benj Sykes (Carbon Trust)

- Offshore Wind Accelerator – drive increased value add
- Need to chow why Olin & gas should get involved (return)
- Size could be 20 – 25GW by 2020
- This is more than a generation of supply chain industry
- Today’s technology will not deliver ‘the Prize’
- Need oil & gas meets the car industry [Compare with Egan report in construction]

Paul Dymond (Oil & gas UK)

- Oil & Gas plans beyong 2050
- Will need to work alongside each otherwiseCould have 40% of UK energy demand met by UK resources if we develop it
- Oil & gas spend £6B in CapEx each year thru'
    - Standard operations
    - Shared logistics
    - Relationships (avoid competition across sector)

2012

Keynote: Ronnie Bronner (RepsolNE – buyout of SeaEnergy)

- RepsolNE buyout of Sea Energy in June '11 is a result of Repsol's decision to get into renewables in 2010
- The capital programme is £3B with £100 ear marked for development stages
    - Site survey
    - Met mast construction & data
    - Grid connection costs
    - Consenting
- Issues are:
    - Supply chain – Oil & gas players, OEMs (turbines)
    - Grid connections
    - Cost reduction – must achieve this; 1st generation projects; come via technology (vessels), productivity, relationships
    - EMR – a worry (change)
    - Capital requirements – must make attractive to 'pure-play' long term, institutional investors

Panel Session: (Jonathan Cole, Iberdrola; Tom Findlay, Repower (now Senvion); Alan Macaskill, KOWL; Robin Presswood, Fife Wind Park)

- JCole: industry is well positioned, competition needed to drive more innovation, Iberdrola would get involved to define standard parts (jackets etc.). It is crucial to be competitive internationally (speed up grid, consents). Tier I suppliers getting there but lower tiers need to move faster
- TFindlay: Should standardise where no IP; need a Europe focus (i.e. Germany, Denmark, UK not just Scotland); Scotland is 1/3 resource – so twice as much outside Scotland as in; parts expectation changes (large casting could be in UK).
- AMacAskill: If we don't speed up we will be caught; procurement discussion start now for 2014 build; CONTRACTS snowball is starting to roll, looking at relationships to drive productivity.
- RPresswood: Tier 3s are only hearing opportunity, not seeing real work; public investment in infrastrucutre just beginning (ports)
- Q&A points;
  - We lack test sites for technology (e.g. NAREC); need onshore test sites open to all
  - Utilities need to support innovation to move things ahead
  - European funding is moving to the demonstration stage; cost is in much more than just the turbine; need smaller projects to build up to the big ones (round 3)
  - Alliances can help 'kick-start' the next stage; no market forces if no market, we will see the market from the business behaviours
  - Getting more consents through so confidence up (and easier investments); need volume commitments in market (Government); looking for JOINT investment with the supply chain
  - There will be a competitive benefit for the early movers (not necessarily first movers)
  - SME's need to get in at the bottom (like in oil & gas); low value items e.g. oils, consumables

Alliances discussions

- Fife council is working on infrastructure and planning; it can focus to get the consents in place for eventual investments

- The public sector has created the opportunity BUT government need to let it run independently otherwise there will be; too much bureaucracy; returns will be not on PROJECTS but on industry take-off (compare a tethered kite to a soaring glider)
- Ormonde experience – build out ahead of schedule, no lost time to accidents

Innovation Lessons (Phil de Villiers – Carbon trust)

- Innovation doesn't come from the places you expect; genuine breakthrough is rare, even the best ideas need detail development
- Take advantage of the commercial opportunities to trial; e.g. twisted jacket as a Met Mast foundation; minimise worries for investors; get the risk / reward level right – extra subsidy for extra innovation
- Learn about the latest innovation; need to spread the word to listening ears
- See what it takes to build an industry from our competitors; i.e. long term R&D; use research institutions strategically; build on our strengths

Energy Market Review, this will be make or break for Offshore Wind Power

- Need the carbon Floor Price; this will manage the failure of the European Emissions Trading Scheme (ETS); need to remove Climate Change Levy (CCL) exemptions
- The 'Capacity Mechanism' will impact on the wholesale price
- CfD is very different to ROCs; 2-way instrument; is it the same CfD if baseload or intermittent (different cost base); will there be indexation
- Vattenfall OK about the mechanisms but concerned about the timescale; concern over electricity market liquidity in UK
- Vestas still planning the Sheerness production site but now looking for the order pipeline to justify.

Project round-up

- All optimistic – includes Argyll Array and Islay Array projects which were rused permission and/or withdrawn

Summary session:

- Deep water, far offshore sites can now been seen happening in Scotland

- Operations & Maintenance needs to be brought in (could be ¼ of total cost of energy)
    - Regulatory environment; limits reach of small craft to 60NM of safe haven; if over 12 occupants becomes a passenger craft (prove safe for grannies and babies)
    - What types of vessels? Likely not a single solution; new innovations don't always reduce cost. Solution when 60km offshore>
    - Windcat building 30 vessels; need to be fast; operate in at least 2m mean wave height

2013

Keynote: Niall Stuart SR

- Lord Stern report highlights OWP matters
- £165M invested in Scotland due to OWP
- Previous year has built doubt due to EMR – risks and questions
- The core questions answered but the big remaining question is 'UK Government commitment beyond 2020'

Keynote: Lena Wilson (Scottish Enterprise)

- Fast growing industry
- 10GW in plans for Scottish waters
- Inward investors coming to Scotland – Areva, Gamesa, Samsung
- It's a big challenge, but also a big opportunity.

Keynote: Alex Salmond

- Recognise what has already been achieved – targets of Scottish generation (31% by 2011, 50% by 2015) have been, will be met
- Government cannot give certainty, but can give clarity – we need to show there is intent beyond 2020, proposed a goal for 2030
- Use targets to provide assurance of government intent (not to limit success)
- Believe the industry is nearing a tipping point.

Keynote: Dan Finch EDPR

- Moved from lines on a map 6 years ago to concrete proposals that can be consented
- Built up the information needed for consenting; environment effects, tides, sediments, marine life
- Government needs to resource the consenting process – consents coming through will help reduce risk / market uncertainty
- Need a vision beyond 2020 (e.g. 2030); expectations, targets etc. By end of 2013 will have enough projects to meet 2020 targets
- Supply chain needs to invest in meeting the opportunity; vessels, O&M facilities
- Why Scotland? Scottish Government enthusiasm; offshore wind is longer term investment than onshore, the resource is here, the skills are here.

Parallel session 1

- CRTF report moving from £140 - £100 /MWhr
- But local content (London Array content low)
- Need cluster synergies – consenting process, construction & installation, vessels, consolidate spares
- Sustainability of the market from: regulatory framework; forward visibility of projects; clear economic benefit to the market (c.f. nuclear etc.)
- Andrew Jamieson – need more collaboration, reduce contingencies, too much competition in these early stages. Everyone waiting for the utilities to get their chequebook out – need to build consortia so everyone contributes

Project Update:

- MORL (Craig Milroy, EDPR): Making progress, spend will take off in 2015, (local) supply chain not getting involved – likely 1/3 of what it could be, the developer will only contract with a few tier 1s, SMEs need to get with these companies.
- Neart Na Gaoithe (David Sweenie, Mainstream): Consent decision in 2013; FID late 2014; build 2016. Project website show supply chain dates. Expect £1.4B in FID
- AREVA (Andrew Bellamy): Focus on Germany (Bremerhaven) but will work with export if viable. Need to look beyond UK market for a viable supply chain. Call to compete with German companies.

Parallel Session 2

- Support organisations; ORECatapult, ETP, AREG
- Need to give the market a more coherent focus (OREC)
- Map (technology) demand to university resource (ETP)
- Deploy & demonstrate NEW concepts (AREG)
- Developers focussed on consent NOT technologies

Project Updates

- MORL
- Neart Na Gaoithe
- Greater Gabbard / Walney
- Beatrice
- SeaGreen
- Inchcape

2014

‘From Concept to Reality’

Keynote: Niall Stuart (SR)

- Crucial stage for OWP – a great deal of uncertainty is problematic
- Published figures show the marked slow down; 45GW opportunity in 2010, 12-13GW planned in 2013, 10GW in Scotland becomes 5GW of applications
- EMR concerns; strike prices; FID CfDs (no Scottish projects); allocation process for CfD
- Competition too soon due to CfD process?

Keynote: Eddie O’Conner (Mainstream)

- Disappointed in 2013
- Issues of institutional capacity, route to market, industrial policy. Confusion, inconcictency, delay all seen in Scotland
- None of the 5 Scottish schemes consented yet

- No revenue stream visible = no investment
- EMR taken too long
- Need volume to drive down costs

Keynote: Maggie McGinlay (Scottish Enterprise)

- Challenging sector at the moment
- Need to pursue international opportunities to be part of the Scottish Market – driving players are international not UK.
- Have we given up on installation for an O&M focus?
- Supply chain needs to build and maintain relationships – Technip, FoundOcean, Rovop examples

Q&A

- Scotland can have 100% demand met be renewables
- No future for onshore beyond 2020
- The supply chain that commits, wins. Significant contracts are appearing
- Lots of O&G watching with interest but not joining; Too much return in O&G?

Grid Discussion

- OFTO is just mirroring the grid companies (competition?)
- Process works for transitional projects but future?
- Fully integrated European super-grid is the way forward. Needs new transmission tech (HVDC)

Project Updates

- MORL
- Inchcape
- SeaGreen
- Beatrice
- Neart Na Gaoithe

WTG Updates

- Gamesa
- Areva
- Senvion
- MHI / vestas

Finance

- Opportunity to reduce risk via alliances
- Virtuous circle of build some, learn, improve, build more
- Need vision beyond 2020
- Projects need to be ‘right’ scale
- Need for groups of banks to cover £1B investment (bank limits closer to £100M)
- ‘Bankable’ deals need limited (proven) innovation

2015

Observations:

- Visibly quieter overall
- ‘Dead’ feel to the exhibition
- Much smaller conference programme

Introduction: Niall Stuart

- ‘Another’ critical juncture
- Some key suppliers leaving the sector (SSE?)

Keynote: Maggie McGinlay (Scottish Enterprise)

- Uncertainty continues
- Opportunities here and elsewhere – Germany, France, Baltic states
- Innovation is happening – wind monitoring, foundations, floating wind
- Europe is beginning to pick up offshore wind

Keynote: Fergus Ewing (Scottish Government Minister)

- Scottish Government's role is to support the establishment of a new industry
- Saddened by the lack of UK government ambition for OWP - CfD transition only supports ~ 800MW, well short of the 4GW consented
- Scot Gov had no role in setting post-ROC support - 'not our fault?'
- Looking to use renewables support for Island energy systems
- Still grounds for optimism – risk-based approach to policy (i.e. help reduce); floating platforms; build future offshore power vision (wind, wave, tidal stream)
- Use other support mechanisms are available
- We are near to establishing a new industry - "End of the Beginning"

Keynote Q&A:

- Developers have a role in driving supply chain collaboration
- What about CfD for pumped storage
- Developing Humber cluster – shows what was missed (? - may be BEST place for it); still good news for UK

Plenary 2 – New era for OWP in Scotland?

- Dan Finch (EDPR) – preparing for CfD; letting initial EPCI contracts; projects in France and Poland
- Ronnie Bonnar (RepsolNE) – UK view is; 10 years since last turbine in Scotland; tech has moved forward; Consent has moved forward; Finance has moved forward; CfD challenge is limited budget
- Brian McFarlance (SSE) – partners in projects (2; i.e. not outright); moving to FID in 2016
- Jonathan Cole (SPR) – projects in UK, Germany, France; late comers, moving fast and strong; portfolio of projects (but 7GW off Norfolk coast); Bipolar feel to industry Optimism (4GW in, 10GW by 2020, industrial scale, healthy) / Pessimism (Missed expectations, need to reduce below £100 MWhr - £80?, cynical / political football)

Vision of 2020

- Lack of regulatory vision beyond 2020

- Expect RepsolNE to have 2 projects built & third underway
- Slower build rate makes the industry more sustainable
- EDPR focus on wind power needs more stable power of OWP
- See UK as a stable market but costs of entering CfD are high
- Now exporting skills to other (Offshore Wind) markets

How to improve collaboration to drive costs down?

- Was a lot of collaboration early on but the CfD process scuppered it – information sharing
- Now needs industry level bodies to lead collaboration (e.g. offshore wind programme board OWPB)
- Speed up 12 months from CfD to FID
- Opportunities for cost saving: Technology (turbines, installation tech); Competition (for CfD – supply chain competition is driving companies out they need encouragement); Collaboration (via offshore wind programme board); look Ops & Maintenance stage

What innovation is happening with developers?

- Every project is a new prototype – getting concepts onto market; at scale
- Not investing in SME development
- EDPR is a deployment company NOT an innovation company – OWP changes this
- Innovation & risk focus – alliances are a way to address this

Industry Standardisation? (for cost reduction)

- Counter-point to innovation
- OWIC and OWPB help
- Stream of projects and company shake-out will drive this
- Only Dong (Oersted) has the scale and scope to do standardisation
- Opportunities for standardisation: Health & Safety processes; standard asset management processes; standard operating processes; O&M; grid design

Challenges:

- Lack of site of next CfD (will there be one?)
- What about the £1B of projects that missed the current phase?
- What happens beyond 2020?
- Is the German market any better?
- Need to get to level playing field (all tech) and subsidy free

Session 3 – maximising Supply Chain opportunities

- Has become about displacing the established Danish and German companies
- Siemens £160M investment in Hull is an example
- There is a balancing act between local content & track record
- Opportunities still: Subsea cables; O&M; others have a logic to swap (to UK supply) but it is not a given
- Must give the tier 1s (turbine producers, electrical sub-stations) a reason to swap
- SSE procurement (Sandy Biggar); Scottish Energy Advisory Board set up a Supply Chain Working Group with explicit Terms of Reference; invited 64 sme's to join 25 said yes; Scottish Hydro Transmission will invest £1B 2016 – 2020
- Siemens Energy UK (Matthew Knight); positive about UK place in the world; UK needs offshore (solar is hard here); offshore started elsewhere but 7,00 working here; UK leads in offshore substations; it's all about the pipeline – big enough but we could squander it

Session 3 – what actions to make collaboration happen

- Gen-up and hit the road!
- CfD is helping to drive local content [a supply chain statement is part of the bid]
- Look at ourselves first over collaboration (maybe too competitive as a habit)
- Developers look to put out a few large EPCI contracts – these will require an alliance / collaboration to complete

Session 3 – where should 'seed' money be spent?

- Must be existing companies
- Track record of seeding is poor – better to make the market clear

- Need to see a completed Scottish Port
- will need infrastructure (ports and roads) for O&M

Innovations:

- Floating wind (tension leg platform) – just another foundation; many advantages and floating isn't the main feature
- Offshore Wind Accelerator - £45-60M spend, none on turbine R&D; foundations, cables, vessels
- Floating wind (semi-submersible) – re-uses O&G cables and mooring expertise; swaps some CapEx for OpEx (helps cash flow a lot)
- Comfort of the investors in the innovation is key
- Little interest in innovation for turbine; just got >7MW, need to maximise cost reduction for these; bankability of innovation is poor; keep doing incremental improvements; innovate thru' technology integration

Future for UK Offshore wind

- Trepidation but resolve!
- Dong view (Benj Sykes): ambition is for 6.5GW by 2020 and getting there; believe the industry is thriving (!); looking for levy control framework to spend the money and long term stability (beyond 2020)
- Offshore wind Programme Board (Adam Bruce): should we be pessimistic? There is a place for OWP; cost reduction and clarity are the key; need to provide strong signals to government; and there is a wider european picture
- Areva (Julian Brown): Supply chain has failed to make much of the opportunity; paradox of industry success (tier 1 – good, tier 2 and lower bad); no picture for the lower tiers until AFTER 2020; need a better plan
- Crowen Estate (Huub den Rooijen): even 10GW makes offshore wind a 'real' power source; EMR makes the market highly competitive; loser in the competition may be the Scottish Supply Chain; O&M the last chance?

- EWEA (Justin Wilkes): UK can be an exemplar for Europe; lots of variation across the continent but many countries have a vision beyond 2020 (esp EU interconnect); need to avoid building many small industries
- Dong on costs: Evidenced the cost reduction below £100/MWhr; let contracts across multiple projects
- Areva on costs: Risk and contingency costed into projects; can be a 20% reduction as experience doubles (i.e. don't use contingency)
- Crown Estate: Price is a bad way of costing out risk and uncertainty; knowledge share is a better solution – SPARTA transparent operations data, G9 Health & safety

- Rate of deployment is proportional to the rate of cost reduction
- The perception of a hiatus is the blockage to the supply chain opportunity

2017

Observations:

- Smaller event – single day not 2
- Little buzz about the exhibition
- Who is here

Plenary 1 Paul Wheelhouse (Scottish Government Minister):

- Notable high points in year: Beatrice financial close (£2.6B) gives BiFab 26 jackets, Nigg assembly, CS WindTowers investing to do offshoresMove to compete in European markets
- Working to make CfD clear; NB yet another Sec State with an Energy Brief
- Innovations getting to trial; 2 blade turbine, Hywind floating
- Cost reduction real: 30% reduction since 2012
- Scottish Government Climate Change strategy to 2032 and direction to 2050
- De-carbonisation of transport means MORE renewables required
- Hopeful: UK government's industrial strategy getting real; UK government willing to be interventionist (a bit) – support for floating wind

Plenary 1 Niall Stuart (SR) Scene setting

- Judicial review of Forth and Tay projects will be challenged
- Inward investment SDIC in RepsolNE
- Lots happening (positive) outside the judicial review

Plenary 1 Anne Glover

- Platitudes on innovation

Plenary 1 Jonathan Cole (SPR & OWPB)

- Spending too much time talking to each other – need to talk outside about how well we are doing
- Track record of achieving cost reduction – hit the 2020 target during 2016; big turbines and reduced financing cost
- More still achievable – so offshore wind will be cheaper than new nuclear AND new gas
- Offshore promises and delivers – not just affordable but cheapest.
- Need to sell the message – OWP is a solution to UK problems (not one of them)

Innovation (& Cost Reduction)

- Tony Quinn (ORE Catapult): improve turbine reliability thru' innovative testing (of blades, gearboxes, electical / mechanical coupling etc.))
- Frederico D'Amico (EDF Blyth demo): Demonstrate & test gravity base foundations, 8.3MW turbines, 66kV transmission
- Angus Cooper (Modus Seabed Interventions: Autonomous Undersea Vessels (cf ROVs) reducing survey cost – feed back in oil & Gas
- Ray Thompson (Siemens): Cost reduction thru'; Size of turbines; fewer components in turbines; better installation vessels (hours to install not days); better portside handling; better people & skills; better logistics (lift the nacelle fewer times); better O&M plans (walk to work); cheaper grid connections; cheaper finance

Infrastructure & Supply Chain

- Andy Lewin (ORE Catapult): Building and sharing O&M experience; 10 off case studies after 3 years e.g. hydrogen sulphide leakage solved; proved no need for helocopter access due to increased reliability
- Alan Duncan (BVG): Things getting exciting! (European deployment boom, CfD2 less than nuclear); BUT missed the CapEx opportunity for UK; bigger O&M opportunity
- Andrew Bellamy (8.2 Aarufield): Blade focus for O&M
- Stephen Thompson (Global energy – Nigg): Offshore wind is a success (in England); got a cross-industry group in Scotland, needed a supply chain sub-group to get jobs, give a collective voice; leaving government to speak for supply chain is a mistake (Germany has 3 groups that speak for themselves)
- Brad Rabone (JDR Cables): Collaborate with Dong to get in, give ZERO in-service cable failures; leverage knowledge back and forth to O&G

Q&A

- Reduce contingency by sharing common repair insurance
- Collaborate on Data Analytics; still limited, SPARK is one opportunity

Industry Leaders debate (Brian McFarlane SSE, Sarah Pirie MORL, David Stevenson ScotGov)

- Issue of judicial review (resolved in 2017)
- Scottish projects portfolio: EDPR western development site is the first for which the CfD process is known
- Cost reduction: significant momentum, don’t stop when target hit, push as far as possible
- Economic benefit and VIABILITY: seeing a real future, significant contracts placed (£650M in Scotland), CfD gives visibility of UK content

Appendix 3: Case Study Protocol

A / Overview of the Study

Objectives

The objectives of this study are to investigate the emergence of a new industry sector and to develop a model of this occurrence that helps develop understanding. This understanding will support improved decisions on courses of actions that lead to more sustainable / 'viable' new industries.

Rationale

The case being investigated is offshore wind power in the United Kingdom. The rationale for selecting this case is:

Contemporaneous with the study timescale

Significant industrial endeavour representing large proportion of generating capacity, highly 'visible' activity, part of a network of changing industrial approaches (renewables, circular economy, low resource use economy), potential for 're-industrialising' the UK economy

Substantive questions over whether an industry is national or global – the influence of this is reduced as UK offshore wind installation market is such a large part of the global market (~50%)

Propositions

The propositions or hypotheses being examined are:

- Industries are 'systems'
- the Viable Systems Model provides a framework to build a valid model of industry
- this model increases understanding of the dynamics of emerging industry.
- The VSM like sub-components of the industry are: Financial System, Planning System, Market Regulation System, Innovation System, Installation System, O&M system

Relevance

The broader theoretical and policy relevance of the inquiry is:

- Industries are frequently identified as entities but the definition is flawed (SIC code based, market based, technology based). Using a systems level classification offers a more useful way forward
- Nascent industries are supported by governments around the world. Better understanding of the system level impact of support can lead to better return for the cost of any intervention (implicitly – by government)

Relevant pre-reading for this case is Beer's VSM and RenewableUK's state of the industry reports 2012, 2013, 2015. Useful background on systems approaches can be gained from Checkland, Meadows and Senge.

Introduction Letter

The following is the text of an introductory letter to participants in the investigation. This provides a high level explanation of the objectives of the study and how their involvement in it will pan out.

> Dear <>,
>
> Thank you for agreeing to consider taking part in this research study.
>
> The study aims to fill a significant gap in research knowledge base related to the emergence of new industry sectors and how this can be most effectively supported. It is hoped that the knowledge gained can contribute to a number of areas including government policy approaches, within industry activities to promote its health and how external institutions should engage.
>
> The process is relatively straight forward. I am seeking a one hour interview with a number of individuals with experience of the offshore wind power industry during its early development stage. Informed consent will be sought immediately before the interview, and this letter is intended to provide background information to support that informed consent.
>
> The data gained from these interviews will be anonymised and combined with published information on Offshore Wind Power deployment and industry conference proceedings to develop a comprehensive case study of the industry.
>
> The expected outcome from this study is a systems model of the industry that can support qualitative analysis of the ongoing viability of the industry. The model is expected to be ‘generalizable’ for any emergent industry sector.
>
> Yours Sincerely
>
> Colin Andrews B.Sc (Hons), MBA
> DMEM
> University of Strathclyde

B / Data Collection Procedures

Protection of participants

This study is conducted under the University of Strathclyde's ethics policy.
Informed consent must be gained from each participant. The following text must be read to each participant and their consent to continue gained.

> *'This interview has been requested to collect data for a research case study into Offshore Wind Power business activities. All responses will be anonymised before reporting, identifying only the broad role of involvement 'developer', 'producer', 'academic' etc. The interview is planned to take an hour of your time and you are free to end the interview at any time. Do you have any questions you wish answered before considering giving consent to continue?*
>
> *'Do you now give consent to continue this interview?'*

Data Sources

The following table identifies the desired contacts

Organisation	Position in System	Name	Position
EdF	Developer Organisation	[redacted]	Policy head
Mainstream	Developer (Stand-alone)	[redacted]	Project Lead
ORE Catapult	Innovation Institution	[redacted]	Chief Exec
Scottish Renewables	Producers Organisation	[redacted]	Chief Exec
Burnt Island Fabrication	Supplier - structures	[redacted]	Managing Director
Seimens	Supplier - WTG producer	[redacted]	
MHI Vestas	Supplier - WTG Producer	[redacted]	
Scottish Government	Supporting Institution	[redacted]	Head of OWP
SSE	Developer / producer	[redacted]	
SPR	Developer / producer	[redacted]	
RepsolNE / CSID	Developer / producer	[redacted]	
KOWL	Developer (stand-alone)	[redacted]	Entrepreneur
Atlantis (Tidal)	Left industry	[redacted]	Ex-Mainstream CFO

Additional supporting evidence from interviews may include:

- Internal reports on OWP in UK waters
- Observations of OWP Supply Chain Conference

The case study will be further supported by the published information on the growth of OWP installations in UK waters, the content of the plenary and break-out sessions at the Scottish OWP

Supply Chain Conference 2011- 2018 inclusive and published reports for government and industry bodies.

Presentation of Credentials

Confirm interviewer identity (UoS badge & business card)
Show signed off copy of ethics approval

Logistics

Required equipment:

- Recorder & backup
- Data logging Pen & Notebook
- Spare Pen & basic notebook

Confirm location and time
Identify travel route and timings

C/ Data Collection Questions

Level 1

The following questions provide the core outline of the verbal line of inquiry in the case study. They are to be asked of each participant in as natural way as possible.

1. What is your experience of OWP, and wider?
2. What do you see as the role/success of financing for OWP (financial sub-system)?
3. What do you see as the role/success of innovation activity around OWP?
4. What do you see as the role/success of planning regime for OWP (planning sub-system)?
5. What do you see as the role/success of the energy market (market sub-system)?
6. How would you describe the structure of the OWP industry? OR Are there any aspects of the OWP industry that we haven't covered?
7. Is OWP a successful industry?
   a. What challenges has it faced successfully?
   b. What challenges could have been more effectively met?
   c. What do you see as the future challenges
   d. How might these future challenges be met
8. Who is the industry leader in OWP?
9. Has the ideal OWP 'farm' been identified?
10. Do you think OWP will survive 5 – 10 – 15 years' time
    a. if so what will it look like?
    b. Are there any better territories to undertake this? (Where and what makes it better?)

Level 2

The above level 1 questions are intended to give data to address the core case questions of:

- Does the participant consider OWP an industry?
- Does the participant recognise the described sub-systems of the industry?
- How effective does the participant see the interaction between the sub-systems of the industry?
- What is the participant's assessment of the health of the OWP industry?

Level 3

The collected interview responses will be examined to see what consistent patterns exist across the responses. Of particular interest are:

- Congruence in views of challenges faced by the industry (past and future)
- Commonality of views on the industry and its component parts
- Any divergence of views
- Do people with limited contact with particular sub-systems have a view of them

Level 4

This level of questions relate to the wider integration of information from the variety of sources to consider the whole case. E.g.

- What sentiment lies behind the published data on OWP growth?
- What life cycle stage is the industry at?
- Does the industry have sufficient capacity/capability to meet currently visible challenges.

Level 5

Normative questions about policy recommendations and conclusions, going beyond the narrow scope of the study:

- Appropriate support for emerging industries
- Role for supporting institutions
- …

Appendix 4: Data Sources and timeline of data collection