The role of offshore wind development in the UK socio-technical transition towards a low carbon electricity system

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Abstract

A growing recognition of anthropogenic climate change has led to carbon reduction and renewable energy targets being institutionalised within the UK's energy policy. Meeting these targets will require a fundamental restructuring of the current electricity system to allow for the long term sustainability of electricity generation. This thesis argues that large scale electricity generation from offshore wind technology will have a key role in driving the sustainability transition within the electricity system. It is argued that the offshore wind technology, like other technologies, is embedded in wider social, political and economic institutions. This means that offshore wind is a socio-technical system and its development involves interactions between the technical and non-technical elements which are socially constructed within existing institutions. The aim of this thesis is to contribute to the understanding of the interaction between technology, institutions and actors in the sustainability transition of the electricity system.

The thesis plans to fulfil methodological insights to investigate the factors that affect the development of the offshore wind system within a socio-technical transition towards sustainability in the electricity system. For this purpose, empirical data were generated from 41 semi-structured interviews with principal decision makers in industry and local authority positions, observations of industry and government events, and industry reports and related policy document analysis. The analysis employs a novel analytical framework that draws from two established theories in the literature: the Multi-Level Perspective (MLP) and Social Construction of Technological System (SCOT), and incorporates insights from transition studies.

This thesis finds a new form of interactions between socio-technical elements of the system in the UK energy transition which leads to different transition pathways to a low carbon electricity system with regard to offshore wind development. The thesis provides a broad understanding of the development of the offshore wind system within the processes of socio-technical transition towards sustainability as well as within the UK's energy policy. A number of policy implications and recommendations are also made of relevance to a broad academic and policy focused audience.

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List of Abbreviation and Acronyms

CCC: Committee on Climate Change

CfD: Contract for Difference

CO_2: Carbon dioxide

DECC: Department of Energy and Climate Change

EU: European Union

LCoE: Levelised Cost of Energy

LEP: New Anglia Local Economic Partnership

MLP: Multi-Level Perspective

$MtCO_2e$: Million tons carbon dioxide emission

MW: Mega Watt

MW h: Mega Watt hour

NIE: New Institutional Economics

O&M: Operation and Maintenance

OMS: Operation, Maintenance and Service

RO: Renewables Obligation

SCOT: Social Construction of Technology

SCOTS: Social Construction of Technological Systems

SNM: Strategic Niche Management

SNS: Southern North Sea

SST: Social Shaping of Technology

STS: Science and Technology Studies

TIS: Technological Innovation System

TW h: Tera Watt hour

UK: United Kingdom

USD: US dollar

Chapter 1: Introduction

1.0 Introduction

Electricity is a key part of the survival and economic growth of human societies (Welch and Venkateswaran, 2009). From the late twenty century, social scientists started to study relationships between the electricity system and environmental protection when the hazard of anthropogenic climate change, in particular, was widely realised. This has given rise to scholarly consciousness that the electricity system needs to change extensively in order to address environmental problems (Sovacool, 2014). Within the UK electricity sector changes mean that the electricity system has been confronted with a number of challenges since the mid-twentieth century. In line with these studies, there is a need to focus on interactions between key actors' actions and changes in elements of the electricity system.

This introductory chapter explains the challenges facing the UK electricity system. It provides an overview of UK energy policy and introduces different factors that influence the energy policy landscape which are driving the electricity system to change.

1.1 Challenges to the UK electricity system

The energy sector, including heat and electricity, contributed to two-thirds of global carbon emissions in 2012 (IEA, 2015). The increasing recognition of the hazard of anthropogenic climate change has focused attention on large scale and long term transformation in the energy system towards decarbonisation and sustainability (Winskel et al., 2014, Späth and Rohracher, 2010) which require substantial changes in technologies and the practices within the existing energy system (Parag and Janda, 2014). This creates an opportunity for the UK electricity system to transform towards sustainability. Moreover, the electrification of other systems such as transport and heating increases electricity demand in the UK which emphasises the need for low carbon electricity generation. These factors provide different motives and importance to facilitate electricity system transformation and have shaped the energy policy landscape in the UK accordingly (Shackley and Green, 2007).

This section, therefore, explains the influence of macro factors that were outlined above and demonstrates how this development provides opportunities and incentives for the electricity sector to change.

Since 2008, a global economic recession has also had an influence on UK energy policies by affecting the economic feasibility and therefore creating competition between different emerging low carbon technologies, including renewable technologies (Foxon, 2013). There are also concerns over the security of supply in the short term in line with climate change targets.

The dominant development that has shaped the overall energy policy landscape is the rising concern over climate change and a resultant commitment to international and national targets for carbon reduction. In 2000, the UK in response to the EU Climate and Energy Package adopted the first climate change programme, to reduce carbon emissions by 20% by 2010 from 1990 levels. The UK Climate Change Act 2008 mandates an 80% reduction of carbon emissions by 2050 from 1990 levels (Ekins et al., 2011, P. 47-49). Meeting these requirements necessitates large scale sustainability transitions in socio-technical systems, including electricity (Geels, 2013, Markard et al., 2012, Van den Bergh et al., 2011, Smith et al., 2010).

These targets and ambitions require a significant development of renewable technologies (Simona, 2012) as low carbon sources of energy supply. The Intergovernmental Panel on Climate Change (IPCC) special report on renewable energy sources and climate change mitigation emphasised the role of renewable energy technologies as a key driver to meet carbon emissions targets (IPCC, 2012). The Department of Energy and Climate Change (DECC) reported that the electricity sector reduced UK carbon emissions by 50% overall from 1990 to 2015 (DECC, 2016a). Therefore, the electricity supply sector is recognised as a key contributor to meet UK carbon emission targets.

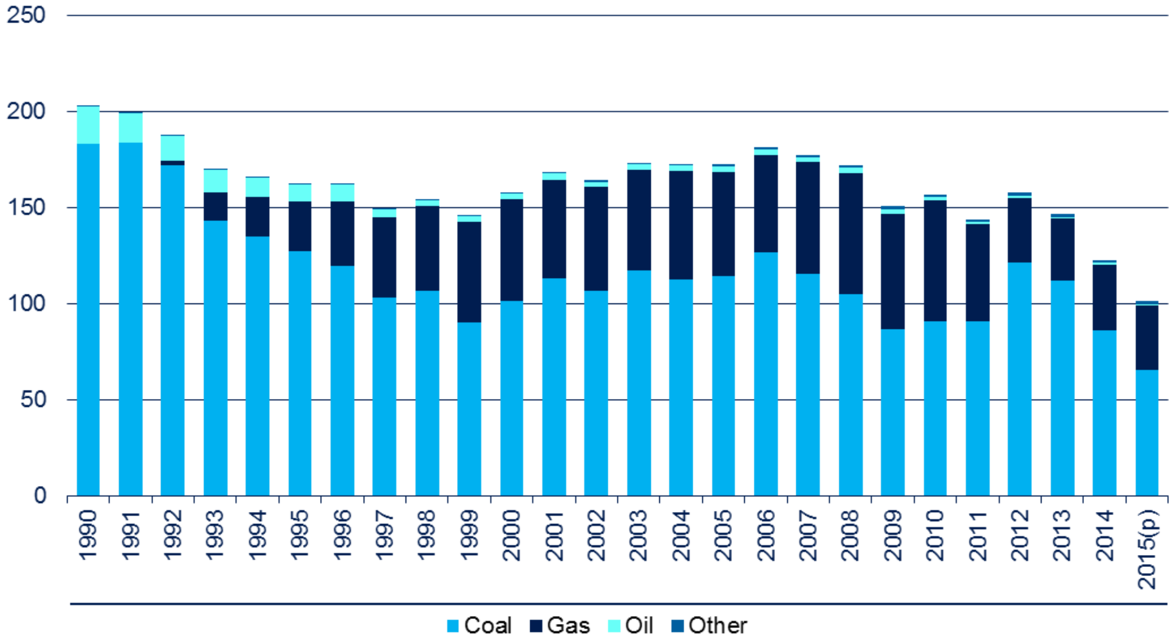
As Figure 1.1 illustrates, overall carbon emission was relatively high from electricity production, especially between 1990 and 2008, due to the use of coal, which means that this sector has the potential for further carbon emissions reduction (Geels, 2014). The impact of the 2008 economic crisis created a window of opportunity for positive solutions for a sustainability transition in the UK electricity sector (Geels, 2013, van den Bergh, 2013), with a resultant carbon emissions reduction between 2009 and 2011, as a switch from coal and oil fired power stations to gas fired power stations was achieved, combined with development in renewables capacity.

The UK Renewable Strategy considers policy implications to tackle climate change regarding its commitment to the EU 2008 Renewables Directive (EU202020), which includes 20% carbon emissions reduction, 20% increase in energy efficiency and 20% of total energy consumption to be generated from renewable sources across Europe by 2020. In response to EU202020, the UK government promoted renewable energy sources for electricity generation, with a target to generate 15% of total energy consumption from renewable sources by 2020 (Higgins and Foley, 2014, Ochieng et al., 2014, Heptonstall et al., 2012, Foxon et al., 2010). To meet this target, it is estimated that more than 30% of total electricity generation will have to be generated from renewable sources by 2020 which will require more than 15 GW to be generated from offshore wind (Heptonstall et al., 2012). Offshore wind is therefore anticipated to make a significant contribution to the UK's renewable energy target.

However, rising oil and gas prices and the Russia-Ukraine gas conflict in 2005, then led the Labour government to prioritise energy security over climate change targets (Geels et al., 2016, Carter and Jacobs, 2014, Kern et al., 2014). Energy security target emphasises three main dimensions: long-term security of supply in terms of availability of supply associated with economic developments (affordable price and competitive supply) and sustainability goals (IEA, 2007, P.160).

In addition to energy security target, an ongoing recession impacted on political prioritisation towards economic austerity and caused a decrease in public support for renewable energies (Geels, 2013). This resulted in an increase in the use of coal, especially between 2012 and 2013 as is also depicted in Figures 1.1. Since 2013, there have been improvements as a result of changes in electricity generation by using a mix of energy sources, growing renewable energy sources and improving the technologies that are used by the energy industry (DECC, 2016a).

Figure 1. 1 UK CO_2 emissions from electricity generation, 1990-2015, ($MtCO_2e$)



Source: Energy Statistics data (DECC, 2016a).

Another issue is that the demand for electricity is increasing over time, which leads to concerns over the availability of current energy sources to meet this demand while delivering carbon reduction targets. It is anticipated that the future energy system will be confronted by an increasing emphasis on electrification in the energy mix to meet the energy demands of other sectors such as transport and heating and the ongoing decarbonisation of these sectors (Lockwood, 2016, Speirs et al., 2010). It is estimated that a 30% increase in heat demand to electricity leads to a doubling of daily demand for electricity (Wilson et al., 2013). Moreover, the electrification of transport and heating is estimated to increase daily electricity demand by approximately 50%. This in turn leads to demands for energy production improvement (Pudjianto et al., 2013).

In addition to these carbon reduction targets, the UK response to the European Commission's Large Combustion Plant Directive in 2001 limits the use of coal fired power stations, which creates additional pressure on the electricity sector to enable the replacement of the electricity generated by coal. The targets and policies being developed highlight the importance of the development of alternative and clean technologies from renewable sources to meet the carbon reduction obligations and to fill the increasing electricity production gap (Wilson et al., 2013, Foxon et al., 2010).

The UK government has played an active role in promoting the development and deployment of low carbon technologies. However, in a general sense, the government has been criticised for its non-intervention commitments to market-based policies (Geels, 2016). It is also noted that: *"the market-based policies have not ensured innovation and deployment of new energy technologies to address the long term challenges facing the UK"* (IEA, 2007, P. 176). The focus of the market-based policies is to provide economic incentives for incumbent firms through institutional frameworks, therefore, these policies are less likely to be able to achieve more sustainable solutions for the electricity system.

The transition to a low carbon electricity system requires large scale technological change as well as changes in policy and institution frameworks (Shakely and Green, 2007) to enable the development of more low carbon technologies and to reduce carbon emissions in line with the targets set. Together social and technological changes in systems like electricity means that changes of this type are often referred to as socio-technical transitions (Geels, 2011). In line with social change, innovations play central role to enable technological change in the electricity system. Next section explains the role of innovations in socio-technical transitions.

1.2 Innovation and technological change for socio-technical transition

Socio-technical transition in the electricity system will require innovations and technological changes which are embedded in broader economic and social settings that develop at the system level (Kern, 2012). The focus is on the functionality of innovations to deliver low carbon technologies within social structures and institution settings aimed at the achievement of sustainable solutions for the electricity system as a societal function. This means that changes in such societal systems in general, and the electricity system in particular, require *'linkages'* between a wide range of elements (Geels, 2004b, P.900) and are based on co-evolution between society and technology (Kern, 2012).

To incorporate these elements into this research and to provide a more comprehensive analysis of the interplay between the elements, the analytic focus needs to be broadened to the whole socio-technical system. Sustainable development studies tend to focus on how *'incremental change'* can be incorporated with the established technology within a system to meet sustainability goals (Kemp 1994, Berkhout 2002, Unruh 2002).

In contrast, literature on transitions to a low carbon economy is interested in the investigation of changes in institutions by addressing the processes of policy makings in a wider political, social and economic context (Scrase et al., 2009).

Technological change is assumed to provide sustainable solutions for emission reductions (Thalmann, 2007), and thus addressing climate change issues requires fostering innovation in the processes of technological change towards the deployment of low carbon technologies in the electricity system (Dechezleprêtre et al., 2016). This requires embedding the social problems of climate change and carbon emissions into the strategies and decision making processes of industries to enable investment in technological change.

Above all, environmental problems such as climate change require structural changes to the electricity system as a socio-technical system which are locked-in to unsustainable mechanisms. So, technological change, as well as changes in institutions and practices, is required (Geels, 2011). Innovations and technological change are essential elements for socio-technical transitions which co-evolve and are interlinked (Geels, 2004a). Although these elements are important, the social aspects are also essential in the processes of transition. Therefore, developing an understanding of transition processes will necessitate an analysis of the social (non-technical) aspects of the socio-technical system.

In order to respond to the social aspects of socio-technical transition and to provide broad understandings of the processes of change, a central concern is to include the constructive role of social actors in institutionalising policies and in shaping technology and practices which has not been fully developed in the literature. This integrated approach is a current gap in the literature which would benefit from further research.

With regard to the electricity system, landscape pressures (such as climate change and economy recession) shape energy policies and have resulted in setting quite ambitious targets and commitments for carbon emission reductions and for a shift towards more renewable electricity generation technologies. This study shows that these targets and commitments place pressure on industries and policy makers to achieve long term sustainability goals and thus foster innovation and technological change.

However, these targets are challenged by lock-in to existing systems and technologies, which can lead to incremental technological innovation rather than a wider structural change in the electricity system.

A socio-technical system analysis of the UK offshore wind system is proposed for this research to enable the barriers and enablers for sustainability transitions to be better understood in their wider political, social and economic contexts.

1.3 Overview of offshore wind development

Offshore wind technology is known as a low carbon source of energy and is considered as a potential displacement for the large scale combustion of fossil fuel (Snyder and Kaiser, 2009). It is argued that offshore wind energy is a key part in the UK energy balance and contributes to electricity system transition. The development of offshore wind in the UK is feasible due to the excellent natural resources available to install and operate offshore wind turbines. The advantages of offshore wind over onshore wind are the stronger offshore winds, the lower visual impact, less audible noise emissions, and reduced land use (Ochieng et al., 2014, Breton and Moe, 2009). This thesis therefore focuses on offshore wind since this technology currently has the most potential to be deployed and developed to contribute to the UK's electricity transition towards sustainability and renewable low carbon sources.

The cost of low carbon technologies, specifically offshore wind turbines (taking into account the costs of offshore installation, operation and maintenance) are relatively high (Esteban et al., 2011, Zhixin et al., 2009). However, technological change is key for low carbon economy growth (Stern, 2006). Offshore wind, like most forms of low carbon technologies, needs public subsidies and policy support for further development and to offset the initial higher costs of such new technologies (Heptonstall et al., 2012). Climate change commitments have been key elements leading policy makers to prioritise low carbon innovations and the deployment of low carbon technologies (Stern, 2006). Innovation in the energy sector can be a significant driver for the policy response to climate change mitigation and other sustainability goals, such as long term carbon emission reductions (Foxon et al., 2008), which are also highlighted in the Low Carbon Transition Plan of 2009 (Ochieng et al., 2014).

The development of offshore wind in the UK has been integrated in three rounds. The first round launched in 2000 for twelve offshore projects, with over 1000 MW installed. Since the early 2000s, offshore wind has been a promising source of energy for transition to a more sustainable electricity system. Round 2 commenced in 2003, and includes seventeen offshore wind projects, with 7.2 GW generating capacity.

The third round commenced in 2009 for leasing 36 GW of capacity. In the 2000s, the deployment of offshore wind has increased rapidly to maintain the UK leadership role in terms of deployment and ambition for the development of offshore wind (Kern et al., 2015, Verhees et al., 2015, Kota et al., 2015, Toke, 2011, Kern et al., 2014, Higgins and Foley, 2014). Total offshore wind installed capacity with Round 1 and 2 projects, combined with the development of Round 3 which is in the planning stage, estimates to generate 40 GW of electricity by 2025. According to this scenario, the UK should achieve its renewable target by 2025 (Higgins and Foley, 2014).

The current UK energy regime is dominated by large scale fossil fuel plants with carbon capture and storage applications, nuclear power and recently the rapid development of offshore wind. Actors in the socio-technical regime for the UK electricity system include the Big Six utility companies (EDF, E.ON, SSE, British Gas, Scottish Power, and N-Power), which is an effect of liberalisation of the electricity market. These utility firms largely generate electricity from fossil fuel plants and some renewable sources (Geels et al., 2016). In addition, there are government agents (DECC and Renewable UK), investors (UKTI) and a powerful system builder in the form of the Crown Estate (Kern et al., 2015) which awards sea-bed leasing (Toke, 2011) within the socio-technical regime for the electricity system. The role of consumers has, however, remained passive (Foxon, 2013, P. 17).

The aim of this thesis is to show that the development of offshore wind requires an analysis of the *'systematic interaction'* (Hughes, 1987, P. 45) between different elements of the socio-technical transition in the electricity system. The study pays particular attention to offshore wind development and attempts to show that to a large extent, offshore wind is a socio-technical system which enables a sustainability transition within the electricity system. In this way, offshore wind system will become a more important part of the energy regime in the future. Therefore, it is proposed that the thesis can contribute to an understanding of transition processes within the electricity system, leading to policy recommendations for a sustainability transition in the UK which can be useful for other sustainability transitions and other countries.

1.4 Research objectives and questions

The main aim of this research is to show how offshore wind will contribute to a transition towards low carbon energy generation in the UK electricity system in the future. The offshore wind system contains both technological and institutional elements that are characterised by the involvement of a range of social actors. This research considers the systematic interactions between all of these elements. The thesis aims to explore new forms of interactions between social actors, institutions and the technological development taking place in the electricity sector in the UK and particularly in the East of England coastal region and with the development of the offshore wind system. The guiding research question for this thesis derives from the broad context that is outlined in this chapter:

What are the effects of the socio-technical transition processes on the development of the offshore wind system to transform the electricity system towards a more sustainable configuration?

To answer this research question the thesis adopts a qualitative and mainly inductive methodology. The most *'influential actors'* (Pinch and Bijker, 2012, P.23 & 28) from the offshore wind sector are interviewed. In this study the purpose is the transformation to a low carbon electricity system.

The main research question will be answered by addressing particular aspects of transition processes with reference to the following supportive questions:

1. *How do non- technical and technical factors affect the development of the offshore wind system within the UK energy regime?*

This thesis aims to make a key contribution to uncover the socio-technical characteristics of the offshore wind system within transition processes. It is proposed that the analyses of technological (technical) and social (non-technical) elements of the offshore wind system illuminate the interconnection between multilevel social groups of actors and therefore broaden our understanding of the role of the development of offshore wind in the overall transition to sustainability within the electricity generating system.

2. *How are the transition processes within the energy regime affected by offshore wind development? What are the effects of the interaction between levels in the socio-technical transition processes on sustainability transition?*

The main objective of this research is to understand the role of the offshore wind system within the process of transition. The aim of these questions are to illuminate the interactions between the current electricity system as the established socio-technical regime and the development of the offshore wind system, while the landscape for the electricity sector challenges both current and developing systems. By asking this question the aim is to explore the co-evolving linkage between the existing electricity system and offshore wind development in the wider policy, economic and social context.

3. *What is the role of social actors in the processes of socio-technical transition towards a sustainable low carbon electricity system?*

The constructive role of social actors in analyses of socio-technical transition processes has received less attention in other transition studies. Therefore, the aim of this question is to explore the dynamic interactions that occur during socio-technical change within networks of social actors to develop insights which are relevant to policy makers and the energy industry in the UK.

1.5 Thesis structure

The thesis is structured into the following chapters:

Chapter 2: Literature review

Chapter 2 first looks at socio-technical transition processes and sustainability transitions through the lens of transition theory. The aim is to explore the theoretical solutions for sustainability transitions. It is argued that although transition literatures provides useful insights to address the research questions, there is a lack of discussion and analysis of the role of social actors in transition processes. To address this, Multi-Level Perspective (MLP) and Social Construction of Technological System (SCOT) theories are drawn on to develop a novel analytical framework which is able to analyse the interactions between multiple elements within socio-technical transition processes. The framework provides a deeper understanding of the social aspects for framing institutional change and allows an exploration of the role of actors in shaping and institutionalising technological innovations.

Chapter 3: Methodology

Chapter 3 explains the methodology used in this thesis. It explains the research design and justifies the adopted philosophical paradigm underpinning this research. The research adopted a social constructive philosophical worldview since the development of offshore wind system is socially embedded in institutional settings. Institutions are seen as social (inter-subjective) realities that are created and institutionalised by multilevel actors through a series of interpretive processes. In order to capture these realities, the research implemented a qualitative methodology based on semi-structured interviews to understand how social actors interpret these realities. This chapter also details other sources of information that were used in this research and explains the thematic analysis used to operationalise and conceptualise the analytical framework.

Chapter 4: Findings and analyses

Chapter 4 presents a number of inductive themes which emerged from the interviews to analyse the processes of transition through interaction mechanisms between social groups of influential actors, offshore wind technology development and institutions within the electricity system. The empirical findings address the three interrelated research questions. The data analysis reveals the effects of the technical and social aspects of socio-technical elements which are characterised by social actors and the interactions between these elements within the electricity sector (Research Question1). The interactions of multiple levels (niche, regime and the landscape) are also included (Research Question 2). It is then argued that human actions can also change the institutions to develop a new technological system to meet the increasing social demands towards sustainability (Research Question 3).

Chapter 5: Discussion

Chapter 5 examines the empirical data and focuses on how theories apply to the research findings. The discussion chapter demonstrates how this study informs the existing literature. The chapter reveals new forms of interaction between social actors, institutions and technology in the UK transition pathway to a low carbon energy system with regard to offshore wind development. The chapter uses context specific knowledge developed in chapter 4 to pluralise insights regarding the sustainability transitions in the socio-technical system. It is illuminated that the transition can be developed in a number of pathways in the UK electricity regime. A number of possible pathways are developed to show how the analytical framework of this thesis discovered the novel interactions identified throughout this research to contribute to knowledge in transition studies.

Chapter 6: Conclusion

Chapter 6 is the concluding chapter and presents an overview of the final conclusions from this research. The chapter reflects on the theoretical and empirical contributions of the thesis, and policy implications and recommendations. It also outlines the limitations of the research and identifies areas for future research.

Chapter 2: Literature Review

2.0 Introduction

The previous chapter outlined elements that are important for the electricity system to change towards a more sustainable system. This chapter aims to explore the theoretical perspectives to understand the socio-technical transition processes in the UK electricity system. While there is increasing academic interest to seek to evaluate the dynamics of changes in primary systems, like the electricity system, this thesis aims to focus on socio-technical transition and to contribute to the existing literature by focusing on transition within the UK electricity system.

In the field of transition studies, scholars have been increasingly concerned about the changes that occur within socio-technical systems in the process of transitions. These studies include four main frameworks: strategic niche management (Kemp et al., 1998, Schot and Geels, 2008, Raven and Geels, 2010, Smith, 2007), transition management (Rotmans et al., 2001, Loorbach and Rotmans, 2006, Kern and Smith, 2008), the multi-level perspective (Geels, 2002, Geels and Schot, 2007, Geels and Kemp, 2007), and the technological innovation system (Markard et al., 2015a, Bergek et al., 2008, Markard and Truffer, 2008).

These studies explained theoretical approaches, using different terms, for analysis of the processes of socio-technical change. Therefore, these studies are collectively referred to as transition theory in this thesis.

The study of socio-technical transitions provides a broad understanding by analysing interactions between multiple elements within the system and its context. In the electricity system, it is argued that change in institutions and therefore the institutional framework, results in a shift to a market-based system, which is led by managers (Verbong and Geels, 2010) and aims to provide economic incentives for more feasible paths (Kemp et al., 2001). To develop a new and more sustainable technological system, like offshore wind, the environmental performance of low carbon technologies will need to improve in key areas such as price and performance (Geels, 2010, Kern, 2012). These environmental improvements, typically, will be achieved through innovation.

Since, the electricity system has distinct links with the wider political, economic and environmental context (chapter 1), and changes require a broad analysis of interactions between multiple elements, this thesis will adopt the multi-level perspective on socio-technical transition and the social construction of technological system as key theoretical lenses. The Multi-Level Perspective (MLP) and the Social Construction of Technological System (SCOT) theories are drawn onto develop an analytical framework which is able to analyse the interactions between multiple elements within socio-technical transition processes.

Therefore, this chapter first critically reviews existing literature in socio-technical transition studies and sustainability transition studies. It then uses relevant indicators that influence socio-technical transition processes. Drawing on these insights, the analytical framework is developed in this chapter and conceptualised in chapter 4. The conceptual framework contributes to recent studies in the transitions literature and uses transition theory to address climate change issues and challenges around sustainability transition in the electricity system. A robust theoretical background is established to underpin the argument of this thesis.

2.1 Transition in socio-technical system

The emergence of global warming and climate change issues caused by carbon emissions, Chapter 1, (Fuenfschilling and Truffer, 2014), and considering the socio-economic trends such as economic constraints (Kern, 2012) and energy resource scarcity (Fuenfschilling and Truffer, 2014, Geels, 2011) require structural changes in primary systems such as electricity (energy), transport, and agri-food systems. Addressing these issues and their effects entail the restructuring of technology (Elzen and Wieczorek, 2005, Geels, 2011) and institutional frameworks and thus involve long term processes. These changes in primary systems, which are termed *'systemic changes'* by Geels (2011), are known as *'socio-technical transitions'*, since they involve changes in policy, markets, user practices, and cultural meanings, as well as new technologies (Geels, 2004b, Geels, 2010).

A system approach provides a broad view to analyse systemic change. Taking the electricity system into account, a description of the term *'system'* is required. Fleck (1993) characterized a system as *"complexes of elements or components, which* *mutually condition and constrain one another, so that the whole complex works together, with some reasonably clearly defined overall function"*.

Therefore, from a system point of view, the system concept implies that changes in a system, or systemic change, are complex and long term processes that are based on co-evolution and the interdependence of technology and institutions (Markusson et al., 2012, Fuenfschilling and Truffer, 2014, Geels, 2011). Because these systems entail physical artifacts (technologies) and knowledge (Geels, 2004b, Markard, 2011), institutions and networks of multiple actors, these systems are conceptualized as socio-technical systems (Markard et al., 2012).

Based on insights from Thomas Hughes' (1983) study on the emergence of the electrical power systems, a socio-technical system concept focuses on the processes of social structures (institutions) and technological change, and emphasises co-evolution and the interdependence of these two patterns at the same time (Markusson et al., 2012). In this respect, Hughes (1986) explains that the technology can be seen as a *'seamless web'*, and Rip and Kemp (1998), similarly, view technology as *'configurations that work'* (P. 330). Both these academic works indicate that for technological development, multiple elements such as physical artifacts (technology); science, research and development (knowledge); regulations; organizations (manufacturing, firms, businesses, investment bodies); and natural resources should combine together, particularly for technological systems like electricity.

Unruh (2000) considers a technological system as *"inter-related components connected in a network or infrastructure that includes physical, social and informational elements"* (P. 819). Based on Hughes' insights, the development and evolution of technology and the social and institutional aspects, are essentially linked, co-evolved and interrelated with each other. They cannot be separated and collectively provide the fulfillment of a societal function (Rip and Kemp, 1998, Geels and Schot, 2010). Callon (1987) views technology as being broadly embedded in its context and emerging from the interaction of technical elements and social worlds, which includes systems of beliefs (P.132). Based on this perspective, the term socio-technical is therefore more appropriate than the term technology.

The transition approach is in a broader context discussed to explore the relationship between innovation and technological change at the sectoral level. Foxon et al. (2008) view innovation broadly as *'production, diffusion and use of new and economically* *useful knowledge'* while Tidd and Bessant (2001) emphasise the development of new products and/ or processes when practices at the industry level. Innovation is distinguished in four main types according to Freeman and Perez's taxanomy:

First group, known as incremental innovations, refer to continuous innovations to improve the existing products and services through *'learning by doing'* and *'learning by using'* with fewer effects from deliberate R&D activities. On the contrary, the second group namely as radical innovations refer to those discontinuous radically new products and services which result from deliberate R&D activities. Third group is distinguished as technology system, which is combination of radical and incremental innovations, refer to *'far reaching'* changes in interrelated technology and economy elements which result in a new sector. Techno-economic paradigm as the fourth group is characterised as a combination of interrelated product, process, technology, organisational, and managerial innovations. Changes in this setting result in new technology systems which have pervasive influences throughout the whole economy as well as the emergence of new products and services. These changes involve transformation of social and institutional framework associated with a deep structural change in the economy (1988, P. 45-7).

This taxonomy provides a useful perspective on innovation whilst Freeman (1994) extends the focus to *'clusters of related innovations'* which entail a wide range of products and services that affect the whole system (such as electricity system). This view points out how the complementarity of interrelated elements, such as technology and innovations, and existing technological systems within established institution settings can possibly contribute sustainable solutions for social problems, such as climate change and carbon emission reduction.

Socio-technical transitions involve changes in institutional structures in addition to the technological aspects and so differ from technological transitions. Socio-technical transitions incorporate sets of complementary technical and non-technical elements that are necessary for the development of technologies to fulfill societal functions. So, these changes affect societal domains relatively such as policy making, user practices, planning and infrastructures. For example, for a transition in the transportation system and the automobile as a technology, institutional frameworks are required to change, such as traffic rules, insurance, user practices, and the complementary development of the fuel supply system, road infrastructure and maintenance (Markard et al., 2012).

Geels and Schot (2010) classify socio-technical transitions by four main characteristics. First, socio-technical transitions are co-evolution processes that lead to change in socio-technical systems. Socio-technical transitions require the development of new technological innovations through knowledge and artifacts and involve the societal processes of embedding new technology such as regulations, markets and cultural meaning. In the field of transitions studies, scholars; for example, Geels (2011) and Markard et al. (2012) include multiple elements such as policy and political structures, regulations, standard and norms, market, infrastructure, and cultural meaning which are collectively referred to as institutions in this thesis. Change in socio-technical systems is a long term and complex process (Fuenfschilling and Truffer, 2014) because technologies are embedded and intertwined with institutional structures (Markard et al., 2012, Geels and Schot, 2010, P.11-12).

Second, change in socio-technical systems simultaneously affects actors as well as technologies and institutional elements (Fuenfschilling and Truffer, 2014). These actors comprise multiple social groups such as industries and businesses, politicians and policy makers, consumers, researchers and engineers (Geels, 2011, Markard et al., 2012). Therefore, socio-technical transitions are multiple actor processes that involve interactions between multiple social groups (Geels and Schot, 2010). However, multiple actors reproduce, transform and maintain technologies and institutions elements (Geels, 2011) into a stable form of configuration to deliver specific services for society such as energy provision (Fuenfschilling and Truffer, 2014) or a sustainable electricity system. Geels and Schot (2010) term configuration as '*the alignment between a heterogeneous set of elements'* (P. 12). Therefore, the societal configurations are considered to be achieved through interactions between multiple social groups.

Third and fourth, socio-technical transitions are long term processes, around 40-50 years or more that lead to fundamental and radical shifts in socio-technical systems in terms of the scope of change (Geels and Schot, 2010). This means, within transitions processes, new products, services, business models, and organizations (manufacturing, firms, investment bodies, research and development) substitute or complement the existing systems. Transitions involve a wide range of multi-dimensional processes of change in technological and institutional structures including: physical, policy and institutions, economic, and socio-cultural meanings. As cases in points, historical studies on socio-technical transitions include studies on the transition from surface water to piped water (Geels, 2005a) and the shift from horse-carriage to automobiles

(Geels, 2005b) and the hygienic transition from cesspools to integrated sewer systems (Geels, 2006a).

To sum up, the approaches reviewed in this section have illustrated transition processes in socio-technical systems based on the four characteristics: co-evolution, multiple actors, radical change, and long term processes. As a starting point, it has been evaluated that both technology and institutions are linked and interdependent on each other and thus are equally important for system transitions analysis. Secondly, transition is a shift between socio-technical configurations involving new technologies as well as interrelate changes in institutional structures.

2.2 Sustainability transition

Transitions towards sustainability, similar to socio-technical transitions, are long term and multi-dimensional processes involving multiple actors. However, within the processes of change, established socio-technical systems shift to more sustainable forms of production and consumption in for example, energy, transport and agri-food systems. Sustainable transitions are therefore different from other forms of historical transitions (Markard et al., 2012, Coenen et al., 2012, Smith et al., 2005, Geels, 2005b, Geels, 2005c). Transitions to more sustainable systems, (within the energy system for example), increase the possibility of environmental efficiency (Verbong and Geels, 2010). In order to provide a broad understanding of the concept, the characteristics of sustainability transition need to be reviewed. Transitions towards sustainability, in some certain characteristics, differ from historical transitions. Geels (2011) characterises sustainability transitions according to three characteristics.

The first characteristic that makes sustainability transitions different from historical transitions relates to desirable solutions in response to environmental problems; for example, change in institutional frameworks to support *'green'* technologies. In this respect, sustainability is understood as the best possible way to achieve the *'goal'* that is intended. Therefore, sustainability transitions are *'purposive'* and *'goal- oriented'* differing from emergent transitions based on resources and capabilities that were observed in historical forms of transitions (Smith et al., 2005, Geels, 2011, Markard et al., 2012).

The challenge of being goal-oriented is to emphasise the outcome; for example, carbon emission targets: for the UK there is an 80% carbon reduction target by 2050 compared with the 1990 levels (Foxon, 2013). This means that sustainability processes include with groups of multiple goals that are *'ambiguous'* and *'contested'*; but aim to provide a *'collective good'*. Multiple actors can therefore pursue diverse interpretations of problems, follow different discourse and interests, and advocate dissimilar directions to the particular solutions in relation to social, economic and environmental aspects (Meadowcroft, 2011, Geels, 2010, Markard et al., 2012). Well-known cases of discourse in sustainability transitions have been studied by Kern (2012). In his study, Kern used the MLP to stimulate socio-technical transitions for policy assessment.

The second characteristic indicates that the outcomes of the sustainable solutions in socio-technical transitions towards sustainability are unlikely to be able to offer users promising benefits. Sustainable technologies compared with existing technologies *"score lower on price and performance dimensions"*, since sustainability is understood as goal-oriented and a collective good. So, in order for new and sustainable technologies to be commercialised or to replace existing technologies, changes in institutional frameworks, such as the introduction of subsidies and taxes, are required (Geels, 2011).

The third characteristic refers to placing sustainability transitions where greater demands on systemic change are observed, such as energy, transport and agri-food sectors, especially related to environmental problems. Sustainable technologies or innovations are able to address the environmental issues. The challenge is that these sectors are dominated by large and incumbent firms which rely predominately on unsustainable technologies, have sufficient economic resources and often have strong political lobbies to resist transition. However, these firms do respond to environmental problems by supporting *'green experimental projects'* (innovations). This is only possible as a result of certain social actors successfully raising environmental problems and arguing for solutions and change (Geels, 2010, Geels, 2011).

The third characteristic of sustainability transitions can extend to a new strand indicating the role of existing firms in processes of sustainability transitions. Incumbent firms access resources and hold complementary assets such as manufacturing, complementary technologies, distribution channels, networks, and markets, which are important for commercialising green innovations. In return, incumbent firms create strong positions through their involvement in developing environmental innovations. Through reorientation of these existing resources and complementary assets towards sustainability (supporting environmentally innovations), incumbent firms are able to strengthen their competitive position and to increase the possibility of cost efficiencies (Rothaermel, 2001, Bohnsack et al., 2014, Geels, 2011).

In terms of technological change, sustainable technologies that intend to deliver environmental goals; such as green innovations, are developed during the process of transitions. Since technologies are embedded in institutional structures (Hughes, 1987), the challenge is to change relevant social structures in order to achieve sustainable technological change. Existing systems, such as fossil fuel based energy generation, are unsustainable in the long term, but are locked in through intertwined and co-evolved technological and institutional processes such as economies of scale, sunk investment, learning processes and competencies, and policies, discourses and beliefs. These lock-in processes emerge as a result of the path dependency of technologies and institutions path-dependency that affect the existing systems' stabilities (Geels, 2011, Unruh, 2000). Rosenberg, (1994) defined technological change as being path-dependent, which means it is predominately based on the improvement of existing technology. This technological change, rooted in incremental innovation, reflects the current stock of knowledge, which is shaped and influenced by an accumulation of past knowledge.

The creation, coordination and continuity of new knowledge, skills and resources (Unruh, 2000) are important for change in social structures and to dislodge the existing systems from lock-in mechanisms and accordingly allow technological change towards sustainability. This leads the discussion to the importance of learning processes in processes of change. Dosi et al. (1988) suggests that technological change, at the micro level (also referred to as the niche level), refers to learning process characteristics which relate to the price of production and the transfer of resources from low-return to high-return employment or skills (P.32). New technologies are often expensive and do not perform as well as existing technologies in some aspects and so they need to undergo continuous improvements in price and performance (Geels and Schot, 2007, Geels, 2010, Kern, 2012). In this respect, Unruh (2000) points to the importance of skills, knowledge and resources in the development of new technologies. He also highlights the effective roles of industries and firms, funding bodies and educational institutions in the creation of standardisation, in the development and support of new technologies, and to understand social demands.

To sum up, the processes of transition towards sustainability involve ambiguous perceptions of environmental problems, and contested views about particular solutions for environmental problems and the appropriate policy instruments to support them. So there is a need for shared visions; because, sustainability is a 'collective good' goal (Geels, 2010, Geels, 2011, P.25). Therefore, the direction of sustainability transitions requires agreement and cohesive views within the sectors and by multiple actors. This leads to concerns about the importance of enhancing knowledge and understanding to identify the problems in specific sectors (like environmental problems) and to inform the most appropriate transition direction. Studies on learning processes imply that the problems in systems can be facilitated based on available knowledge and experience. Taken together, learning processes and those complementary assets that emerge from the existing settings (existing knowledge and resources) are used to create new knowledge and skills that are necessary to solve systems' problems. This in turn helps systems to dislodge from path-dependency, to improve performance and price of production (efficiency of products), and accordingly to achieve economies of scale.

2.3. The theoretical perspectives on socio-technical approaches

2.3.1 Introduction

Transitions towards sustainability require systemic change in primary systems such as the electricity system. These changes require innovation and technological development, particularly low carbon technologies that are able to address environmental problems and institutional frameworks to support these changes (section 2.2). Since these systemic changes are co-evolved and interdependent of both technological development and institutional frameworks, these changes aim to achieve social and economic prosperity as well.

Based on the literature on socio-technical transitions, there are two main schools for theorising transitions. The first is based on new institutional and evolutionary economics theories and focuses on the role of institutions. New Institutional Economics (NIE) emphasises the importance of transaction costs, while evolutionary economics highlights the role of technology and innovation only as the basis of institutional change (Dosi, 1982, Dosi and Nelson, 1994, Nelson and Winter, 1982, P. 24-25). In relation to sustainability transitions, changes in socio-technical systems require long term processes of socio-economic paradigm shifts (Geels, 2010, Geels, 2005d, P.57-60).

This literature, therefore, has illustrated the interactions between economic, technological, social and political factors (Meadowcroft, 2011).

The second area of theorising transitions broadly stems from Science and Technology Studies (STS). The STS theory developed when Williams and Edge (1996) emphasized the importance of the *'content of technology'* rather than the outcomes of technological change. They propose the Social Shaping of Technology (SST) as a strand of STS. Williams and Edge's (1996) study on SST provides a broad understanding of science and technological innovation in relation to social science concerns.

Although NIE and evolutionary economics consider that technology is socially shaped, they do not particularly pay attention to the constructive role of actors. However, Bijker and colleagues (1987) propose the Social Construction of Technology (SCOT) to draw on the history and sociology of science work. Although the important role of social actors has been raised by scholars such as Genus and Coles (2008) and Geels (2010), there is still an absence of the constructivist role of social actors in research on analysis of the sustainability transitions processes. There is not therefore a conceptual framework for sustainability transitions which interprets the role of actors. To better consider the role of actors, there needs to be a constructivist approach combined with transition theory. This thesis will therefore combine the constructivist stance from SCOT and combine this with transition theory. The SCOT theory emphasises the role of multiple social groups of actors in the processes of sustainability transition, including the interpretations and sense-making of institutions, and the development of a specific technology within its context.

2.3.2 Transition theory

In the studies of sustainability transitions, the socio-technical system has been used as a framework to inform the transition approach and to recognise multiple interrelating factors that influence technological systems. Transition theory provides a broad understanding of the stabilisation of existing socio-technical systems and involves the analysis of interactions between the multi-levels: niche innovation (micro level), socio-technical regime (meso level), and external landscape (Rip and Kemp, 1998, Geels, 2002, Smith et al., 2010, Rotmans et al., 2001, Elzen et al., 2004, Geels, 2011, Verbong and Geels, 2010).

For socio-technical systems, a review of the academic literature illustrates that under transition theory four main areas of research have developed. The first group of research that developed on the concept of transitions studies proposed a theoretical approach to analyse technological change. These studies explain the dynamics of transitions through the empirical analysis of a number of historical transitions. These studies were developed by Frank Geels (Geels, 2002, Geels, 2005b, Geels, 2005a, Geels, 2006a, Geels, 2006b). Further to the cases explained in section 2.1, Verbong and Geels (2007) have also analysed socio-technical energy transitions and systemic change in the Dutch electricity system.

These studies on historical analyses of technological systems identified the conditions under which transition processes develop. These analytical approaches have been developed by Geels (2002), Elzen et al. (2004), Rip and Kemp (1998) and are conceptualized by the Multi-Level Perspective (MLP) which explains technological transitions through the interplay of dynamics of the three analytical levels (niche, regime and landscape). The MLP draws upon earlier work and insights from evolutionary economics, history of technology, science and technology studies, institutional theory, sociology of technology, and innovation studies (Geels, 2002, Geels, 2005d, Grin et al., 2010) to understand technological transitions. Research on transitions has further developed based on these fundamental studies (Markard et al., 2012). However, the strength of the MLP is for research on sustainability transitions.

The second group of research developed on the basis of the knowledge of transition studies for developing processes of interventions, governance and transition management. Transition management is built upon insights from complex system theory by (Kauffman, 1996) and governance studies by Rotmans et al. (2001), Smith et al., (2005) and Markard et al. (2012) and has been broadened in wider scientific research (which includes innovation, history, ecology, sociology, political, and psychology studies) to address environmental problems and achieve sustainability goals (Kemp et al., 2007, Loorbach and Rotmans, 2010). Transition management developed through experiments and practices (systemic change) within existing sectors in regional and national environment and policy projects, aiming to direct transition processes and to influence governance activities, and to accelerate and to guide social innovation processes towards sustainability goals (Kemp et al., 2007, Loorbach and Rotmans, 2006, Loorbach and Rotmans, 2010, Geels, 2010).

As a case in point for these transition experiments, transition management, initially as a novel mode of governance for national policy-making implemented for the Fourth National Environmental Policy Plan for the Netherlands (NMP4) developed through the insights from systems innovation to address the environmental problems within societal domains (systemic change), aimed to achieve sustainability goals (Geels and Schot, 2007, Meadowcroft, 2005, Loorbach and Rotmans, 2010). The strength of transition management is that the governance process structures a *'transition arena'* to promote social learning processes by multi-actors who share goals, visions (Kemp et al., 2007), debates, experiments and thinking (Markard et al., 2012). This social learning process, therefore, creates the conditions to develop and to scale up breakthrough innovations which provide future opportunities (Loorbach and Rotmans, 2010).

The third strand of research has employed the MLP to develop *'socio-technical scenarios'* (Hofman et al., 2004). These studies explore potential future configurations for ongoing processes within socio-technical systems and seek transition pathways towards the implications of those configurations. These studies have built upon work by Elzen et al. (2004) and Hofman et al. (2004). More recent work on transition theory falls into the fourth strand of research. This research has increased the use of the MLP as a heuristic for the analysis of policy, developing a convenient policy framework to inform sustainability transitions. This research builds upon insights from innovation studies and systems innovation developed by Kern (2012). This strand of research, in contrast with work on transition management which aims at analysis for policy, contributes to the analysis of policy within socio-technical transitions towards sustainability. This line of research uses transition thinking to provide policy frameworks for sustainability goals, since ambitions for sustainability require societal efforts to realize long term processes so as to achieve change (Meadowcroft, 2011) when overwhelmed by environmental problems.

These four contributions that emerge from transition thinking are significant. The purpose of reviewing these four main perspectives was to use them as a platform to develop a novel theoretical and analytical framework. This thesis seeks to address the challenges of systemic change, focusing on a sustainability transition in the electricity system. The basis for the research framework in this thesis is drawn upon these four perspectives and the following sections which provide more in depth insight into the research framework.

2.3.3 The multi-level perspective theory for sustainability transitions

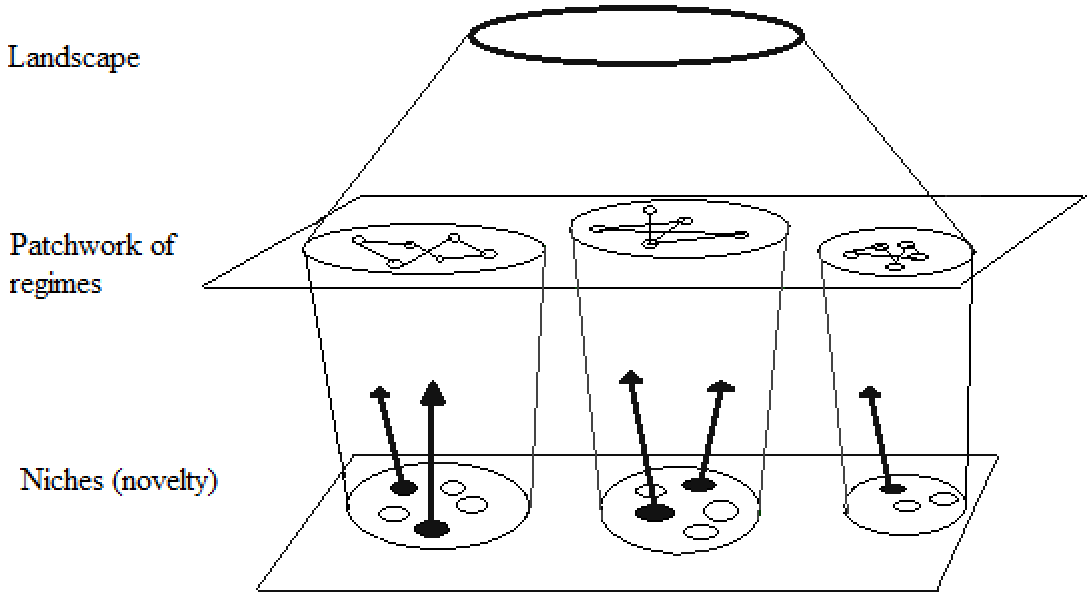
The multi-level perspective (MLP) (Rip and Kemp, 1998, Geels, 2002, Geels, 2004a, Geels and Schot, 2007) is an important theory for analysing sustainability transitions in various systems, such as energy (Geels, 2010, Verbong and Geels, 2007, Loorbach and Rotmans, 2010, Fuenfschilling and Truffer, 2014). The MLP is a middle range theory (Geels, 2007) that is able to frame specific topics like sustainability transitions, and to be enriched with combining concepts (for example, it incorporates interpretive/ constructive theory) through its flexible framework (Geels, 2010, Geels, 2011).

The MLP provides an analytical framework based on a combination of theoretical assumptions from evolutionary economics (to provide insights for analysis niche and regime path dependence and routine), science and technology studies (to provide insights for analysis sense-making, social groups of actors, and the more importantly to understand technology that is shaped as a result of social processes by wider societal context), structuration theory and new institutional theory (to provide insights for analysis rules and institutions that structure actors' actions) (Geels and Schot, 2010, Geels, 2011).

From the MLP lens, transition is understood as *'multi-dimensional'* (non-linear) processes that occur from the outcomes of the *'interactions'* between the three analytical levels: micro level (niche) which is the centre for radical innovations, meso level referring to existing practices that have stabilised in a socio-technical regime, and an external socio-technical landscape (Geels, 2004a, Geels and Schot, 2007, Geels and Schot, 2010, Verbong and Geels, 2010, Geels, 2011, Geels, 2002, Geels, 2005b, Rip and Kemp, 1998). Therefore, the MLP provides useful insights for the analysis into a socio-technical system of niche, regime and landscape levels, while it conceptualises the whole dynamics in socio-technical transitions.

Geels and Schot (2010) characterise the three analytical levels as *'heterogeneous configurations'* of socio-technical elements which depend on the degrees of stability and the size of elements and alignments between them to provide different structuration and coordination in relation with, for example, rules and actions by actors (P.18-19). Since transitions occur through interactions between these three analytical levels, the link between the levels can be seen as a '*nested hierarchy'* (Figure2.1).

Figure 2. 1 Multi-levels as nested hierarchy



Source: Adopted from Geels (2002).

In early MLP studies, Geels (2005c) and Geels and Schot (2007) explain the structure of transition processes and how the embeddedness of regime-landscape and niche-regime within socio-technical systems is key to analyse the interactions between dynamics at these levels (Geels, 2005c). Furthermore, the MLP focuses on the social groups of actors, and their strategies, interactions and beliefs (Geels, 2011). This falls into Raven's study on Strategic Niche Management (SNM), which notes that within socio-technical systems changes emerge from practices in niches where take place outside of the stable regime. Transition scholars believe that these niche spaces are less structured, but have more scope to accommodate actors' activities, such as the learning and experimentation processes needed for new idea, technology and innovation (Raven, 2005).

Geels (2005d) believes that within socio-technical systems, rules and actors are interrelated, since rules and institutions coordinate and guide the actions that actors take in order to maintain and to reproduce socio-technical systems (P.16-17). Later, Fuenfschilling and Truffer's (2014) studies on the structuration of socio-technical regimes, take additional insights from institutional theory. Fuenfschilling and Truffer (2014) highlight the focus of socio-technical systems specifically on technology and the interconnection of materials and social elements. This shows that institutional concepts (such as rules) have been added to the MLP.

From the MLP point of view, the niche and regime levels are surrounded within a wider context, including sets of social and physical factors, that provide a macro level structuring for the socio-technical system as a whole (Smith et al., 2010, Verbong and Geels, 2010). Taking into account that transitions are about changes to the socio-technical regime i.e. regime shifts, these changes within the socio-technical regime occur in three interrelated dimensions. The first dimension involves material and technical elements such as resources. The second dimension consists of social groups of actors such as incumbent industries and firms. The third refers to sets of formal and cognitive rules for framing transition directions and guiding actors' practices, for example, belief systems, regulations and guiding principles (Verbong and Geels, 2010).

Therefore, the strength of the MLP relates to the nature of multi-dimensionality that occurs through interactions between the three levels (Geels, 2010, Geels, 2011) which qualifies the MLP as a useful framework for the analysis of sustainability transitions. A transition towards sustainability is understood as a shift from a socio-technical system (which is mainly unsustainable like an electricity coal fired based system) to a more sustainable configuration. However, a system cannot be qualified entirely as a sustainable system. This is because systems (like electricity) entail large and established infrastructures (Verbong and Geels, 2010), and are locked into various existing mechanisms (Geels, 2011). Therefore, a new and sustainable system is less likely to replace the existing system. This result refined early MLP studies which defined transitions as shifts from one regime to another regime.

2.3.3.1 Niche

The niche level concept is central to the MLP (Geels, 2011) and the Strategic Niche Management (SNM) frameworks (Schot and Geels, 2008, Raven et al. 2012) for sustainability transitions. Since sustainability transitions (systemic change) require new and sustainable technologies to be widely implemented (Rip and Kemp, 1998, Elzen et al., 2004, Markard et al., 2012, Van den Bergh et al., 2011). These frameworks suggest strategic support for these sustainable technologies from premature rejection from the mainstream market and incumbent regime, until these new technologies are sufficiently developed in terms of performance, price and infrastructure (Raven et al., 2016b, Garud and Gehman, 2012). So it is important to understand where (new) sustainable technologies emerge and how they develop in order to achieve systemic change (Kemp et al., 1998, Jacobsson and Bergek, 2011, Hekkert et al., 2007). This highlights the importance of niches as the centre for new technologies to emerge and to develop and also indicates that the importance of providing protective space to support the development of sustainable technologies.

Protective spaces can be explained through different approaches (Geels, 2010, Stirling, 2011, Garud and Gehman, 2012). In the transitions literature, the dynamics of protective spaces mainly draws upon four lines of thought: evolutionary, institutional, relational, and geographical perspectives. This study, however, in line with transition theory (for example the MLP) has taken the evolutionary perspective as a starting point. However, studies show that evolutionary and institutional perspectives can be coupled for the study of sustainability transitions and considering geographical perspectives provides a useful understanding on empirical studies that focus on certain technology development that is embedded in a specific location like renewable energies. Table 2.1 provides some examples.

Table 2. 1 Examples of perspectives on sustainability transitions

Empirical focus	Evolutionary Perspective	Institutional perspective	Relational perspective	Geographical focus	Author(s)
Socio-political space for renewable energy	✓	✓		Germany	(Lauber and Jacobsson, 2016)
Empowering sustainable niches for offshore wind	✓	✓		UK, the Netherlands	(Raven et al., 2016b)
Socio-technical transitions in energy policy			✓	Switzerland	(Markard et al., 2015b)
Political and economic aspects of offshore wind energy developments	✓	✓		UK	(Kern et al., 2014)
Sustainable innovation development for solar photovoltaic electricity generation	✓	✓		UK	(Smith et al., 2014)

As Table 2.1 illustrates, evolutionary and institutional perspectives dominate in sustainability transitions research that is interested in the development of renewable energy technology. In the field of transition studies, an institutional approach has underpinned research from the beginning. From an analytical point of view, the institutional approach explains the structure of the institutions' discourse in relation to socio-technical transitions. This perspective enables the formation of protective spaces which are constituted by institutional settings that are ruled by social groups of actors.

Protective spaces, from an evolutionary perspective, support radical innovations and shield them from selection pressures by incumbent regimes (Schot and Geels, 2008). These spaces are constructed through social processes such as negotiations (Howarth and Rosenow, 2014). Spaces from relational perspectives are constituted by interactions and controversies between actors which shape spaces between innovations and context. The geographical perspective, worked by Coenen et al. (2012), Raven et al. (2012) and Truffer et al. (2015) is another area of interest for transitions scholars, which has emerged from evolutionary, institutional and relational approaches. The importance of geography in transition studies increases consideration to the notion of spaces, spatial scales and localities (Raven et al., 2016a).

2.3.3.2 Niche dynamics: protective spaces

The importance of sustainable technologies in sustainability transitions places great emphasis on the role of niches as a source of path-breaking innovations. In the academic literature, niches are characterised as *'protective spaces'* where new sustainable technologies, experiments and practices can develop (Schot et al., 1994, Kemp et al., 1998) by building a number of elements such as social learning processes and performance improvement. These new sustainable innovations are able to break the path of the *'selection pressure'* by the incumbent regime to then start interacting with the regime in the mainstream market (Kemp et al., 1998, Smith and Raven, 2012, Markard et al., 2012, Smith et al., 2014, Kern et al., 2014, Kern et al., 2015, Geels and Raven, 2006). Therefore, niches are key for transitions since they provide path-breaking innovations for systemic change (Geels, 2011).

However, all niche innovations are not path-breaking since socio-technical regimes function as selection environments for the creation and retention of innovations (Rip and Kemp, 1998, Geels, 2002, Smith et al., 2010). Transitions studies argue that co-evolution interdependencies within multi-dimensional processes of socio-technical transitions create various lock-in and path-dependency processes. These lock-in mechanisms make the regime environment selective against the path-breaking innovations, whilst path-breaking sustainable innovations are disadvantageous within these contexts (Smith and Raven, 2012) since they have relatively low performance yet are high in costs. Further to that, insights from the SNM illustrate that there are notions of uncertainty in their functions and an absence of stable and supportive social networks. As a result, new technologies are unable to compete immediately with existing regimes that are locked-in and path dependent on various mechanisms (Geels and Raven, 2006, Geels, 2005c).

These arguments led scholars to recognise the significance of the construction of protective spaces in sustainability transitions. Accordingly, Smith and Raven (2012) conceptualised the structure of protective space into three features: shielding, nurturing and empowering. An evolutionary perspective suggests that protective spaces are constructed through social and political processes (Raven et al., 2016a).

Niches form the protective spaces where sustainable technologies emerge. Protective spaces are important for *'shielding'* these new technologies from the mainstream market selection, for developing learning processes, and for building extensive social networks that support the new technologies (innovations). These protective spaces (provided by niche advocates) are needed because new technologies are generally not reliable enough to be aligned with incumbent technologies, for example in terms of price and performance, so competition in mainstream markets is not viable immediately. Therefore, new technologies need long term *'sustainability practices'* to be able to make radical changes in environmental and economic performance. Arguably, these sustainability experiments are *'hopeful monstrosities'* (Mokyr, 1990, P.291), since they make promises regarding changes in environmental and economic performance (for example, solutions for environmental problems) but at the same time they are monstrous as they do not exhibit reliable performance (Raven and Geels, 2010, Berkhout et al., 2010, Smith and Raven, 2012).

Based on insights from niche innovation studies by Kemp et al. (1998) and Schot and Geels (2008), niche innovation developments are distinguished by three main processes. The first is providing guidance (for example, funding) for the innovation processes by directing the visions and expectations of external actors to support these innovations. The second is building extensive social networks to increase the resources for the development of niche innovations. The third is developing and enhancing the learning processes in various dimensions such as technology design, infrastructure development, and institutions improvement like: market and user preferences, business models, policy instruments, and cultural meanings (Geels, 2011).

This logic, coupled with the SNM insights, highlights the important role of niches for providing spaces for learning processes. Learning processes are important since they affect many dimensions of transition processes, such as, technology and design, infrastructure, user preferences and practices, regulation and symbolic meaning. Furthermore, niches provide space to build the social networks and to expand the networks in order to support innovations. The development of networking between multiple actors across levels (Geels, 2005c, Hoogma et al., 2004, Kemp et al., 2001, Kemp et al., 1998) enables better relationships and more involvement within the supply chains.

Niche actors align around shared expectations and visions with the wider networks which are influenced by changes at the landscape level. This enables the more extensive networks, consisting of powerful actors, to interpret the sustainable innovations and the structure of the transitions, which begin with the destabilisation of the existing regime (Grin et al., 2004, Smith et al., 2010) and start a form of path-breaking.

Within protective spaces, the processes of sustainability transitions are in place when niche actors *'nurture'* the experimental innovations in terms of performance improvements, learning development and building extensive socio-technical networks in order for these experiments to open a new path. In turn, new technologies and innovations can create more robust niche markets and, accordingly, integrate with mainstream markets. Progressively, the need for protective spaces for innovations decreases, since innovations enter more diverse markets. Therefore, at the final stage, the protective spaces can be removed so the innovations are *'empowered'* to act as competitors and become influential contributors that interact with the regime to fulfil transitions towards sustainability.

The SNM also suggests that some developed features of the niche experiments can be institutionalised within a transformed mainstream market so as to propose new routines (Smith and Raven, 2012).

Based on insights from the SNM, niche innovations are real-life experiments which may make it to the mainstream market or may fail. Smith and Raven (2012) believe that niches provide spaces for innovations to develop through multi-dimensional forms which involve diverse factors (Table 2.2). The empirical studies on historical analyses of system transitions (e.g. Geels, 2005c, Geels, 2005b), illustrate the use of these protective spaces within the processes of change in socio-technical systems for path-breaking the existing regime and for linking up with wider processes.

Table 2. 2 Protective spaces

Selection pressure	Protective space
Established industry	Industrial protection
Incumbent technologies	Technological protection
Knowledge, resources and learning paradigms	Socio-cognitive protection
Established institutions	Institutional protection
Prevailing regulations	Political protection
Stabilised cultural value/ symbolic meaning	Cultural protection

Source: Developed from Smith and Raven (2012).

As Table 2.2 illustrates, various selection environments cause pressure on niche innovations that require protective spaces. Smith and Raven (2012) indicate the need for geographical spaces yet they consider them as passive spaces due to the less strategic nature of these variables. However, sustainability transitions are geographical processes which are connected to particular places (Hansen and Coenen, 2014).

On the other hand, the MLP is interested in analysis of the transformation of societal functions within the socio-technical systems where the role of places (in this thesis geographical specification of resources connected to location) does matter for sustainable innovations in transition processes (Smith et al., 2010). For example, in practice, there are many locations where natural resources are accessible to produce more sustainable forms of energy while natural resources are embedded in their locations. However, the studies on geographical spaces have been concentrated on the effects of geography in transitions (Smith et al., 2010).

Path-breaking innovations require multi-dimensional forms of protection, since these selection environments are multi-dimensional (Table 2.2). These multi-dimensional protections create active spaces directly through the needs for specific innovations, or form passive spaces based on the deployment and development of existing specific innovations. However, protective spaces are considered as temporary sites until innovations are nurtured by gaining sufficient improvements over incumbent regime selection environments. So the protective spaces (shields) can be removed and niche innovations are empowered to become competitive and diffuse widely into mainstream markets (Smith and Raven, 2012).

2.3.3.3 Niche internal momentum processes to empowerment

Smith and Raven (2012) distinguish the processes of empowerment of niche innovations as *'fit-and-conform'* or *'stretch-and-transform'*. The first form of empowerment refers to processes under which niche innovations are developed to fit in and conform to an unchanged selection environment, such as existing institutions. The second pattern implies empowering processes in which niche innovations reform institutions which leads to a re-structured incumbent regime. Niche innovations influence the selection environments and so institutions are changed in favour of niches (Geels et al., 2016). The process of stretch and conform is beyond the internal niche process and so involves broader processes within the regime, society and economy (Smith and Raven, 2012).

The academic literature demonstrates that mainstream market selections delay the processes of path-breaking niche innovations. The role of niches is to provide environments that function as a shield to hold off pressures from regime selections and to nurture path-breaking innovations until they are further developed. The path-breaking innovations develop through operating *'experiments'* (Kemp et al., 1998) as initiatives that contain novelty within a socio-technical configuration in order to develop sustainability solutions (Berkhout et al., 2010, Geels and Raven, 2006, Smith and Raven, 2012).

The current niche literature explains that the processes of shielding and nurturing niches operate at local and global levels. The local level refers to experiments in local contexts in terms of specific locations, social networks that lead to creating lessons. More broadly, the global level relates to institutional change and wider social networks consist of regime actors that operate from local experiments, and exchange knowledge and resources to surpass the limits of local contexts (Smith and Raven, 2012, Geels and Raven, 2006, Grin, 2010). The advancement of niche innovations occur through learning processes (increasing knowledge, for example R&D), functional improvements (for example offering lower price technology), expanding the network with regime actors (for example potential investors), and supportive institutional requirements. This enables niches to function as sources for transformative knowledge, skills and capabilities which are interpreted through the regime's structures since niche innovations are expected to align and compete with regimes (Smith et al., 2010, Smith, 2007, Grin et al., 2004, Smith and Raven, 2012).

To provide understanding of how the successful niche innovations (technological niches) create market niches and transform regimes, Geels and Schot (2007) suggest that innovations are required to build up *'internal momentum'* to be able to break the path into the regime. In turn, the studies on niche innovations (Kemp et al., 1998, Schot and Geels, 2008, Hoogma et al., 2004) distinguish three internal processes in order for the development and empowerment of the niches to stabilise and interact with the regime:

The first internal process refers to the modification and the development of *'visions'* and *'expectations'*, because they provide guidance to learning processes, and draw the attention of regime actors to support experiments such as participation in green innovations. The articulation of these visions contribute to advance successful technological innovations to the regime when they are shared by broad groups of actors, and substantiated by ongoing projects in terms of quality or performance improvement and cost (Schot and Geels, 2008, Geels and Schot, 2007, Geels, 2011, Smith and Raven, 2012, Bos and Grin, 2008).

The second internal process in niche development refers to the building of extensive social *'networks'* to develop interactions between social actors, aiming to provide substantial resources such as skills, workforce and capital. For technological niches like wind energy to interact with the regime and to enable widespread diffusion, support is needed from powerful actors such as large energy firms. The success of niche innovations depends on the numbers of powerful actors involved to increase the social legitimacy of technological innovations which contribute to institutionalise some structures of spaces (for example shielding and nurturing) for new routines and standards in transformed regimes (Smith and Raven, 2012, Smith et al., 2010, Späth and Rohracher, 2010).

The third core process in niche development refers to learning processes which are broad and cover multiple aspects of broad socio-technical dimensions. Learning processes include the development of facts and lessons such as specific skills and knowledge that accumulate through practices and experience as well as generating *'learning by doing'* (Arrow, 1971) in supporting the niche innovations (Kern, 2012, Shackley and Green, 2007, Geels and Schot, 2007, Smith and Raven, 2012).

Through these three requirements: expectations and visions are broadly established, the networks of actors become extensive and the alignment of multiple learning processes produce established configurations, and the niche increases momentum to advance into the regime and compete in the mainstream market (Geels, 2011). Therefore, for successful niches to advance into the mainstream market (regime), combinations of those factors that have been discussed in current and previous sections are required. These requirements are developed into an analytical framework and conceptualised for this study (see section 2.7).

In addition, the significant role of niche actors has been discussed by scholars. For instance, Geels and Schot (2007) argue that the role of niche actors is important in interactions with regime actors when they create pressure on the regime to legitimate some structures of spaces (for example shielding and nurturing) as new routines and standards in transformed regimes. Similarly, Raven (2006) and Smith (2007) highlight the important role of niche actors, which is to persuade the multiple regime actors to support new technologies, resulting in pushing the niche innovation into the regime. Although scholars (for example Geels, 2011) indicate the interpretive role of actors, there are few empirical studies and limited theoretical work in this area.

2.3.3.4 Socio-technical regime

The socio-technical regime forms the meso level of the MLP, consisting of a set of established technologies that are socially embedded within institutional and political structures (Bijker et al., 1987, Hughes, 1986). These structures are seamlessly interrelated with the expectations, visions and skills (Kemp et al., 1998) which is known as a *'technological regime'* in earlier studies (Markard et al., 2012). Geels and Schot (2007) review the concept of the socio-technical regime by taking insights from Nelson and Winter's (1982) work on exploring the cognitive routines and pattern development within engineering communities about technological trajectories. This work is extended by further explanation from the sociology of technology (Hughes, 1987, Bijker, 1997), considering the additional actors (such as scientists, policy makers, users, and special interest groups) that are involved in a dominant pattern of technological development.

The socio-technical regimes develop through stabilisation of a number of trajectories such as the existing cognitive routines of engineers, regulations and standards of technological systems (Unruh, 2000), the social adaptation to existing regimes, and sunk investments in existing infrastructure, competencies and assets (Geels and Schot, 2007, Christensen, 1997, P.31).

In addition to technologies, a regime consists of a set of rules (institutions), routines and practices that stabilise the existing system and lock the system into the incumbent regime (Unruh, 2000, Geels, 2002, Shackley and Green, 2007). This argument leads socio-technical regimes to maintain stability through path dependency and lock-in to the three interlinked dimensions. In this regards, Verbong and Geels (2007) extend Geels' (2005d, P. 16) work to characterise these three dimensions. The first dimension consists of social groups and networks of actors (for the electricity regime, this includes for example large firms and government agents). The second dimension refers to rules that guide human actions.

Taking insights from institutional theory, Geels and Schot (2007) distinguish rules as regulative (regulations, standards and laws), cognitive (belief system, guiding principles and innovation agendas) and normative (role relationships, values and norms). The third dimension includes technological elements (for the electricity system, this includes resources, sites and the grid).

Insights from new institutional structuration theory by Giddens (1984) suggest that social actors' values, capabilities and activities are embedded in institutions' structures and social networks which means institutions configure actors. So, actors use and share cognitive rules to take the best action for achieving goals. Actors' decisions and activities also influence formal institutions such as role relationships and normative rule sets. This indicates the duality of structures, because actors also reproduce and transform the rules (institutions) through their activities (enactment) in local practices (niches) (Geels, 2011, Raven et al., 2012).

As a result, actors not only use institutions, but at the same time make rules to enable them to constrain and legitimate some decisions through their actions (interpreting, sense-making). The structures of niches and regimes in terms of network of actors and rule sets are similar but differ in terms of size and stability. Based on the above argument, regime actors perform a stronger constraining influence than niche actors. Therefore, for niche innovations to become regimes, extensive social networks of actors and stable rules are required (Geels and Schot, 2007).

From a theoretical perspective, a regime refers to an intangible structure such as beliefs, heuristics, rules (routines and norms), standardisation, visions, social expectations and promises, and policy models, and it is different from a system (Geels, 2004b, Geels and Schot, 2007 and 2010) that refers to tangible elements that are measurable such as regulations, public opinion, consumption patterns, artifacts, and infrastructure (Geels, 2011, P. 31).

2.3.3.5 Socio-technical regime transformation

Despite the stability exhibited within socio-technical regimes in terms of configurations and the practices of institutions and technologies, and networks of actors, regimes do shift. These changes occur when successful niche innovations take advantage of *'windows of opportunity'* and start interacting with incumbent regimes. Smith et al. (2005) suggest that regime changes are understood as a function of two processes: the first process refers to *'shifting selection pressures'* on the regime, and the second process indicates the *'coordination of resources available inside and outside the regime to adapt to these pressures'* (P. 1494).

They also classified selection pressures on regimes as: (a) economic pressures resulting from institutional structures such as the wider political landscape change, broader social-cultural trends and economic development (Geels, 2004a), and (b) internal pressures from niche innovations that are not *'yet so established as to constitute a regime'* (Smith et al., 2005, P.1495, Kemp et al., 1998, Geels, 2002, Hoogma et al., 2004).

Smith and colleagues (2005) argue that internal niche-regime interactions and external landscape pressures, are fundamental in order to change socio-technical regimes. Therefore, a change in the regime is also a result of changes at the landscape level or a result of interplay with another regime which challenges the regime configurations (Raven and Verbong, 2007, Geels and Schot, 2007, Smith et al., 2010, Smith et al., 2005). This study, in line with the MLP, also suggests that availability of resources such as capabilities and knowledge and the degree of deployment of resources are necessary for transitions (Geels and Schot, 2007, Berkhout et al., 2004).

Since changes in the regime are a means for transitions, early work on multi-level transitions studies described the transition pathways as a change in the existing regime when the emergent radical innovations in the niche break through and take over. However, in large systems like electricity systems that have various lock-in mechanisms (sunk investments and large infrastructures), it is unlikely that the new regime will take over the existing one. Against this background, Verbong and Geels (2010) suggest a refined typology of transition pathways from the work by Geels and Schot (2007).

2.3.3.6 Socio-technical landscape

The socio-technical landscape is the macro-level of the MLP that influences the niche and regime dynamics and structures the socio-technical system. The landscape level includes a set of deep structural trends such as macro-political developments, macro-economic and socio-cultural patterns. While the landscape forms an external context for actors' interactions, this does not determine that niche and regime actors are able to influence these external factors (Verbong and Geels, 2007, Geels, 2005d), because the context of the landscape is stronger compared to regimes that constrain activities within societies. The landscape rather provides *'pressure-gradients force'* and *'affordances'* that constrain changes to established socio-technical configurations for developments across lower levels (Geels, 2005d, P.78, Smith et al., 2010).

The landscape, furthermore, comprises the large scale physical context of society, such as electricity infrastructures. Geels (2005d) distinguishes changes in landscapes into two *'kinds'*. The first refers to those changes that develop slowly, for example changes in political ideologies and environmental change. The second refers to rapid changes such as oil prices and economic depression (P.79). Changes in the landscape provide sources of pressures on the regime level to destabilise the current configurations and thus generate opportunities for path-breaking niche innovations to take advantage. This process is termed a *'window of opportunity'* by transition scholars (Geels, 2011, Smith et al., 2010, Verbong and Geels, 2010).

In sustainability transitions, there is a growing recognition of environmental problems (carbon emissions and climate change, for example) which develops socio-cultural processes at the landscape level. These factors, at times, can 'destabilise' the performance of current regime configurations or, at other times, can 'reinforce' regime trajectories to meet societal needs. New sustainability standards and principles can challenge existing regimes by destabilising incumbent technologies and practices, and actors. This can create value for new alternative forms of niche innovations like low carbon generation, which can perform more efficiently than incumbent technologies within the new context (Smith et al., 2010, Shackley and Green, 2007, Kern, 2012).

2.3.3.7 Transition process

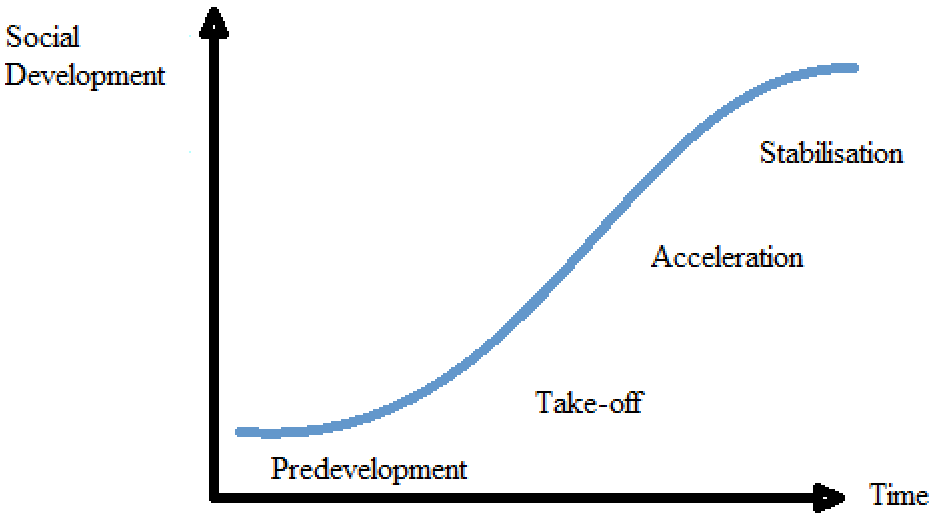
The MLP conceptualises transition processes as the outcome of multi-dimensional interactions between niche innovations, the incumbent regime and the landscape that form socio-technical systems (Geels and Schot, 2007, Verbong and Geels, 2010). Niche innovations build up internal momentum through three internal processes to break a path into the regime, as discussed in section 2.3.3.3. Landscape developments create pressure on the regime from a macro-level and at times it can reinforce the regime to change its normative institutions. This can then destabilise the regime and create opportunity through this window of opportunity for path-breaking niche innovations to break through into the incumbent regime, to compete in mainstream markets and to establish a new market. The processes continue over time and the new regime then starts influencing the landscape.

The interactions between levels can be distinguished into further phases, and there is a link between each phase and a particular mechanism (Geels, 2005b). These phases can be viewed in a S-curve (Figure 2.2) that depicts transition processes resulting from interaction processes, consisting of predevelopment, take-off, acceleration and stabilisation phases (Rotmans et al., 2001, Geels, 2011).

1) *Predevelopment* (emergence) phase refers to a dynamic of stability where the change is not visible.
2) *Take-off* phase refers to the starting point of the process of change when the system shift has started.
3) *Acceleration phase* refers to diffusion, embedding and learning processes, when structural changes have taken place.
4) *Stabilisation* phase occurs when a new configuration is established.

Sustainability transitions can move to new phases, for example from R&D and experimentation processes, which refers to the predevelopment phase, to the take-off phase, which emphasises large scale deployment and development of sustainable solutions such as green technologies (Geels, 2013).

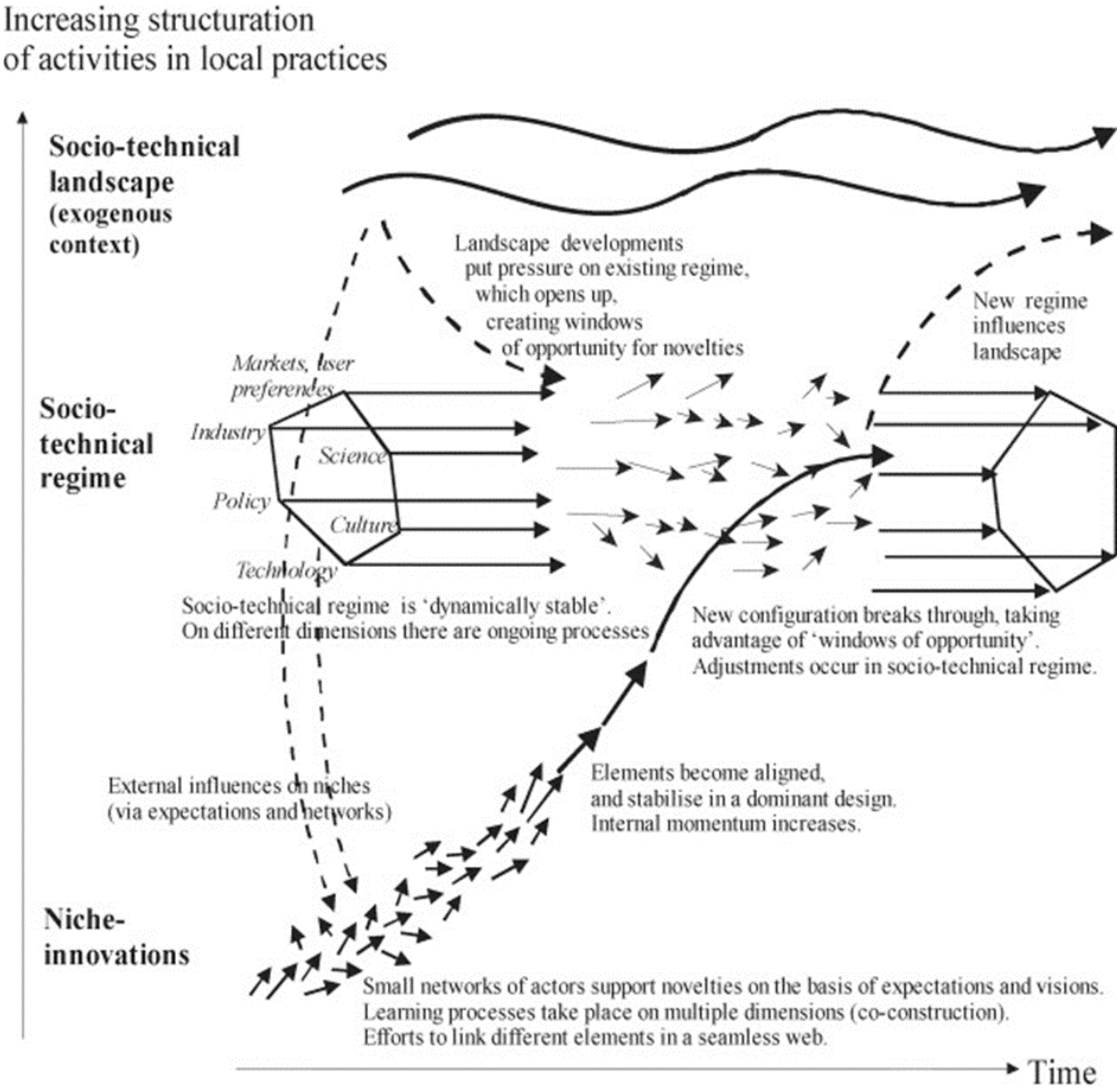
Figure 2. 2 The transition phase



Source: Adopted from Rotmans et al. (2001).

According to early work on the MLP, the processes of transition can be understood as the interactions between three levels. Against this background, Geels and Schot (2007) refined this process when they suggested that transitions can produce multiple outcomes depending on different '*timings*' of interactions between levels. This means that the transition path will be dissimilar, depending on the timing of landscape pressure on the regime and niche innovation's status, in terms of the degree of development of the niche. Figure 2.3 illustrates the processes of transition, developed by Geels and Schot (2007), which is based on early work by Geels (2002).

Figure 2. 3 Multi-level perspectives on transitions



Source: Geels and Schot (2007).

Niche and regime actors may have dissimilar perceptions about the degree of development of the niche. Therefore, broad transition pathways can occur as a result of timings when niche innovations are sufficiently developed. Geels and Schot (2007) argue that a dominant niche emerges through learning processes, support from powerful actors, and price and performance improvements. These indicators which stem out from early works by Kemp et al. (1998), Hoogma et al. (2004) and Geels (2005d), were discussed in section 2.3.3.3, and have been added to the MLP.

With regards to this perception that transitions do not occur simultaneously but through interactions between the three MLP levels, Geels and Schot (2007) identified different typologies for transition pathways. Later, Verbong and Geels (2010) refined these pathways. They propose four typologies of transition pathways, considering different *'kinds'* and *'timings'* of interactions between the three MLP levels. As explained in section 2.3.3.6, the kinds of interactions between levels refer to the nature of landscape pressures which path breaking niches reinforce or destabilise the regime. Timings depend on the adjustment of landscape pressures with developed (path breaking) niche innovations which will result in different transition pathways. These pathways are introduced as follow:

1) *Transformation pathway* refers to external pressure from the landscape level on the regime in order to shift and to reorient the existing regime. Regime actors may experience further pressures by outsider social groups, such as social movement and public opinion. In this pathway, niche innovations are characterised as insufficiently developed to provide solutions and to take advantage of the window of opportunity that is created by external pressures within the regime. So, radical innovations are restricted within the niche. In this pathway, changes are in place, yet modest, through the reorientation of activities (such as changes in guiding principles and R&D investments) by incumbent actors within the regime. As a result, the direction of regime trajectories changes gradually. An important attribution that Verbong and Geels (2010) contribute is that a new regime grows out of the existing one through these processes.

2) *Reconfiguration* refers to a pathway in which niche innovations are able to provide specific solutions for regimes that are under external pressures from the landscape. Therefore, certain niche innovations are adopted into the regime as new components or add-ons such as new technologies, resulting in an ongoing reconfiguration of some structures and a gradual change in some cognitive sets such as guiding principles, practices and beliefs. Similar to the transformation pathway, the new regime develops within the existing one. In contrast with the transformation pathway, in this pathway a change in the structure of the regime occurs through increasing the cumulative adoption of these new components and technologies which are predominately developed and supplied by niche and regime actors through interactions.

3) *Technological substitution pathway* refers to problems and stress in regimes that are produced by landscape pressures. In this pathway, landscape pressures create a window of opportunity, and niche innovations are sufficiently developed to use these opportunities. Therefore, new technologies diffuse increasingly into mainstream markets and replace the existing regime eventually to become the new dominate configuration.

4) *De-alignment and re-alignment pathway*. In this path significant changes in the landscape lead to de-alignment of the regime. The erosion and destabilisation of the regime causes uncertainty in the optimisation of niches due to the coexistent nature of multiple niches and diverse experiments. Finally, the one dominant option emerges through competition with other niches to restructure the regime in terms of new cognitive processes, practices and actors.

Table 2. 3 Summary of the transition pathways and comparison of the actors' role

Interaction / Pathway	Role of niche actors	Role of regime actors	Effect of landscape	Interactions between levels
Transformation	Low	Medium	High	Landscape-Regime
Reconfiguration	Low to medium	High	Low	Niche-Regime
Technological substitution	High	Low	High	Niche-Regime-Landscape
De-alignment & Re-alignment	High	Low	High	Niche-Regime-Landscape

Source: Author

These pathways are influenced by *'social processes'* (Geels and Schot, 2007, Foxon et al., 2010) and therefore more than one pathway can be studied for empirical cases such as the analysis of the electricity system (Verbong and Geels, 2010). These pathways demonstrate how change in socio-technical systems can occur, and which interactions between the MLP levels lead to transition. However, transitions in socio-technical systems are complex processes, involving multiple factors. Socio-technical systems are also complex, involving multi-dimensional processes that occur through interactions between analytical levels, as the review of literature in this chapter has demonstrated. This provides a broad understanding and vision of a socio-technical system which is in the process of change and the need to analyse these processes at a broad system level. This thesis argues that transition in the electricity system is in process through the response to the legal targets for carbon emissions reduction and the development of offshore wind technology as a solution.

2.3.4. The Social Construction of Technological Systems

There are a number of academic works which take a constructivist perspective. Commonly, their arguments are that technological change is the outcome of social interaction processes rather than a deterministic approach. The Social Construction of Technology (SCOT) theory as a constructivist approach suggested by Genus and Cole (2008) and Geels (2010) to address interactions between actors and technology development. SCOT was developed by Pinch and Bijker (1987) and describes the process of technological change as a *'garden of forking paths'* (Williams and Edge, 1996, P.866) with multiple variations and selections. The Social Construction of Technological Systems (SCOTS) evolved from SCOT when (Bijker and Pinch, 2011) demonstrated the important line between the social constructivist perspective and the structural technical system approach (Mayntz and Hughes, 1988) by taking broad insights from Thomas Hughes' (1986) work on *'seamless web'*. The broadening of the constructivist perspective, however, expands the unit of analysis to the broadening socio-technical system rather than the focus only on technical artifacts (Bijker, 1997, Bijker and Pinch, 2011). In that sense, new domains of SCOT reflect the broad construction processes in society which address both the construction of institutions and the co-construction of technologies (Bijker and Law, 1992, Bijker, 2010). Therefore, the SCOTS theory highlights the intertwined characteristics of technology, society and science.

The SCOTS theory embraces the methodological principle of considering how the constructive role of *'relevant social groups'* of actors through their activities (actions and interactions) draws boundaries between technology and institutions. It is against the essentialist views that emphasized only technology and its context, and in contrast with the history of technology perspective that focused on the heroic role of engineers as the inventors of technology. In this sense, the SCOTS theory emphasizes the dynamic role of social groups in shaping and using technology. This emphasis on 'groups' rather than individual actors illustrates the potential volume that enables SCOTS to accommodate more social (inter)actions, particularly in the link with technology. This allows SCOTS to examine different aspects of technologies that are embedded in conventional sociological contexts (Bijker and Pinch, 2011).

SCOT is identified in three main stages. The first stage demonstrates the *'interpretive flexibility'* (Bijker, 1997) of technological artifacts. In the sociology of technology, technological change is conceptualised as a process of sense making. It refers to the demonstration of different interpretations of the emergent technologies that are constructed within a social context (Geels and Schot, 2007). It indicates flexibility in the interpretation of technology based on social actors' thinking. It also demonstrates flexibility in how technology is shaped which emphasizes a number of applicable methods for designing technology. In this sense, social groups of actors can possess different meanings for a particular technology through interpretive flexibility. In the case of the evolution of the bicycle, in the early stages a particular social group of actors emphasized a specific function of the technology, such as speed for sport. However, later in its evolution another social group emphasized concerns over safety. This causes ambiguity and conflict, and may lead to the success of one dominant interpretation over the other (Pinch Trevor and Wieber, 1987, P. 22&33-35).

Arguably, interpretive flexibility is a key factor in shaping environmental problems in sustainability transitions. Geels (2010) argues that sustainability transitions are hindered because social actors possess different interpretations of the scale of environmental problems, and different views about the most applicable sustainability solutions in terms of economic, social and environmental balance. Because sustainability processes involve interactions between different social groups such as public and private groups who seek different goals, it may lead to conflict and disagreement at different stages.

Therefore, it requires identifying *'relevant social groups'* who share the same meanings for a particular artifact and possess a similar interpretation of the problems relating to a particular technological artifact. This means the identification of a problem depends on a relevant social group that constitutes it as a problem, whilst other groups may not consider it a problem as they hold different meanings for that artifact. Therefore, a particular artifact is given the same meanings shared by all members of a certain group. This description can be added to the first stage of SCOT.

In their famous empirical case, the emergence of the bicycle, Pinch and Bijker (1987) demonstrate the negotiation process between diverse social groups who shared meanings of a particular technology. They further emphasise how the negotiation process could shape the new design of a particular technology. The diverse meanings that are proposed by social groups are eventually framed through negotiation and coalition, which reduces conflicts and stabilises the change through various possible solutions to problems. This process demonstrates the *'closure'* of debate which plays a central role in the *'stabilisation'* of technological change. However, closure can occur when a dominant interpretation surpasses others and succeeds the debate (Geels and Schot, 2007). Therefore, closure and stabilisation are the second stage of SCOT.

Closure in technological change involves the creation of a shared *'cognitive'* structure, consisting of goals, problems and solutions, methods, and knowledge. In a socio-cognitive frame, actors negotiate about rules, for example, belief systems, interpretations, guiding principles, regulations. Garud and Rappa (1994) explain that technological systems are negotiated, for instance researchers with different beliefs in competition with each other attempt to interpret technology (P.347). An important closure in socio-institutional dynamics is between action groups such as social movements and special interest groups (Geels and Schot, 2007). Closure between social groups is also significant in sustainability transitions since Geels (2010) believes that a lack of *'shared vision'* hinders the process of sustainability transitions.

The final stage refers to the *'wider context'* when the concept of technological change is understood in the wider socio-political environment. The SCOT approach explains technological artifacts as the meanings that relevant social groups give to them. However, socio-cultural patterns and political trends shape norms and values that influence relevant social groups' perceptions. As discussed, multiple perceptions create diverse meanings of an artifact and therefore constitute different levels of development.

This highlights the role of SCOT in the operationalization of relationships between the technological concept and the wider context (Pinch and Bijker, 1987).

Among all of the aspects that the SCOT theory possesses, a criticism has been raised that it does not provide some forms of political actions in links with technology. In other words, the critics claim that although SCOT is able to make sense of realities, it is not able to change them. However, the growth of the SCOTS demonstrates its engagement with the political and normative problems of technology. This development has been demonstrated through empirical cases such as the study of the role of scientific advice in democracy (Bijker et al., 2009), and work on ethics and technology (Johnson and Wetmore, 2009).

It is important to consider that, although taking a constructivist perspective provides appropriate visions and solutions for analysing technological change within a system such as electricity generation, this perspective is less likely to provide characteristics of the whole system in processes of change, because over time some meanings will be socially institutionalised and embedded in power settings like norms. In his work on the governance of sustainable development Jordan (2008) illustrates: *"Even if society broadly agrees on what a more sustainable future would look like, the underlying causes of (and hence remedies for) unsustainability are likely to be so deeply contested that consensus on even the most basic of policy packages will probably always remain elusive"* (P.28). Similarly, in their empirical case infrastructures in large cities, Graham and Marvin (2001) argue that the '*biased configuration of technology'* (P.297) is deeply embedded in social and economic settings.

2.4 Research gap

This section aims to acknowledge the gap in the literature and develops research questions that are expected to contribute to the existing literature on sustainability transitions, the MLP theory and SCOT theory. Therefore, it attempts to combine elements from different aspects that have been discussed in this chapter into one common theoretical framework.

The review of literature reveals that the MLP provides a useful framework for socio-technical systems analysis and has motivated some studies on sustainability transitions. The literature review shows that, although the MLP theory has been refined many times, it has been criticised for having many limitations. This section explains some of these limitations that are relevant to this research.

The first criticism of the MLP theory is that by including diverse and multiple factors into the three analytical (niche, regime and landscape) levels, there are potential downsides of abstraction into the analysis of the whole system which requires appropriate consideration (Smith et al., 2010). However, it is a possible contribution to analyse multiple interactions caused by multiple actors and diverse factors, and draw a conclusion on the system implications while a balance between complexity and simplification of processes is maintained.

There are four main strands of transition theory: historical analyses, transition management, the MLP, and policy assessment (section 2.3.2). Empirical work based upon transition theory, however, has focused on an analysis of past transitions or an assessment of future configurations. It is acknowledged that there are limited empirical cases that attempt to evaluate ongoing transitions.

A methodological limitation of the MLP reflects on the use of historical cases to validate the MLP, for example the transition from horse carriage to automobile (Geels, 2005b), which have been criticised for being based on *'flawed use of secondary data sources'*. The focus of the historical cases has been mainly on analysing the MLP and exploring transition pathways, rather than on a systematic research (Genus and Coles, 2008, P.1441). This argument illustrates that the MLP is yet underdeveloped in terms of the sources of data and interpretation of information. There is potential for further empirical cases with regards primary data sources using the MLP (Geels, 2011), and this thesis helps to partially address this limitation.

While Genus and Coles (2008) criticise the MLP for the absence of a coherent methodology, its flexible method can position different frameworks for analysing empirical cases, for example technological innovation system (TIS) as illustrated in the study by Markard and Truffer (2008). Geels considers that using compatible social theories to the MLP can enrich empirical cases for specific transition processes like sustainability transitions. This ontology, however, developed the use of the MLP (Smith et al., 2010). Reviewing the existing literature on sustainability and socio-technical transitions reveals that there is a neglect in empirical studies to explain and to analyse the interpretive role of actors within the processes of transitions, even though the role of actors is recognised as vital for example in sense making, cognitive change and institutionalisation (as discussed in sections 2.3.3.3 and 2.3.3.4).

Genus and Coles (2008) reveal that there is a need in the MLP to *''show a concern for actors and alternative representations that could otherwise remain silent''* (P. 1441). Further to their argument, it has been suggested by scholars that for a comprehensive analysis of the niche-regime interactions, it is important to incorporate constructivist approaches (Genus and Cole, 2008, Smith et al. 2010) such as SCOT, since alignment in the MLP is enacted by social groups (Geels, 2011). Constructivist approaches highlight the entrenchment of beliefs, for example about *'uncertainties'* incorporated within processes of socio-technical transition (Genus and Cole, 2008).

It is acknowledged that the MLP pays less explicit attention to the role of both incumbent regime and niche actors. This is a reflection of the main critique on the transition theories and the MLP in particular, about the niche-regime interactions, such that successful niches can empower to change to a regime (Geels and Schot, 2007) which is institutionally embedded (Geels et al., 2016). It is unlikely that a regime will be subject to shifts in response to all forms of developed niches equally (Raven, 2006). A regime can co-opt elements of a radical niche innovation with no need to be transformed (Smith, 2007) through a variety of interactions between niche elements and regime components (Geels and Schot, 2007, Smith et al., 2010). The effects of the developments at the landscape level on the regime depends on social actors' interpretation and subsequent mobilisation (Geels et al., 2016) and on the '*timing'* and the *'kind'* of pressures. So the transition does not necessarily occur in a single pathway, but can shift between different pathways.

These arguments collectively indicate that, there is room to pay more attention to the conceptualisation of the role of involved (influential) actors in regime-niche interactions.

Although this flexibility is not acknowledged as a limitation of the methodology, it is a particular contribution which can be broaden the MLP. Taking a constructive approach can produce a novel analysis of various overall patterns and multiple factors that affect ongoing transition processes. This thesis, therefore, contributes to develop the theory and expand the horizon of the interaction mechanisms through the development of possible pathways and the interpretive role of social actors in shaping technology development (Genus and Cole, 2008) in transition processes.

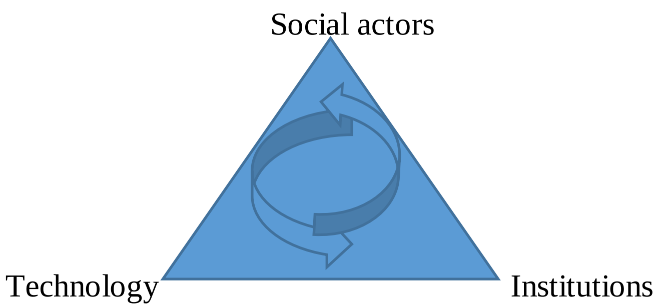
Finally, although the MLP involves the transformation of societal functions, the role of geographical conditions, with regards to the embeddedness of particularly offshore wind technology to natural resources and location has been insufficiently developed within the MLP. Betsill and Bulkeley (2007) suggest aspiring cities collectively can empower, nurture networks and lobby for support by doing sustainability projects jointly. Regions can provide *'political deliberation'* through their locations, resources, local knowledge, and mobilisation of local practices (Healey et al., 2003, P. 86, Smith et al., 2010). This thesis attempts to explore and analyse the role of geography in transitions which expects to yield further insights to analyse the relationships between the niche and the regime. It is then a contribution to the work by Raven on protective spaces.

2.5. Theoretical framework and research questions

Many theoretical frameworks were considered during the literature review in order to add to the MLP. However, the research aims to explore the constructive role of multilevel actors in the processes of transitions. Therefore, an actor-centric theory with an interpretivism perspective (SCOT) was selected as appropriate to form the research framework.

The analytical framework attempts to showcase the insights that have been collected from the existing literature, considering the role of actors in shaping technology and in constituting institutions and analysing the interactions between them. The research framework (Figure 2.4) illustrates the socio-technical nature of the technological system whilst it recognises the co-dependent and context embeddedness nature of elements (technology and institutions) within the socio-technical system during the processes of change.

Figure 2. 4 Theoretical framework: Socio-technical system



Source: Author

The criticisms play a central role to spotting gaps in the literature. This thesis expects to contribute to knowledge from three aspects: theoretical, methodological and contextual. The research framework incorporates SCOT on the sociology of technology and draws insights from the MLP, to frame the research and to extend knowledge and understanding of the socio-technical transition towards sustainability within the UK electricity system. This framework provides a great degree of analysis of the role of social actors in relation to technology and institutions, since it focuses on the interactions between these three main parts of the system.

Therefore, it provides wider insight into the understanding of the role of actors that affect these interactions to inform socio-technical transition towards a more sustainable electricity system.

This thesis aims to address issues around sustainability energy transitions in the UK electricity system. The main research question is:

What are the effects of the socio-technical transition processes on the development of the offshore wind system to transform the electricity system towards a more sustainable configuration?

Three overarching questions address the gaps in the existing literature on sustainability transitions:

1. How do non- technical and technical factors affect the development of the offshore wind system within the UK energy regime?

   The aim of this question is to understand how social actors characterise the offshore wind system and how they interpret the interactions of the multiple factors that affect the development of the offshore wind system.

2. How are the transition processes within the energy system affected by offshore wind development? What are the effects of the interaction between levels in the socio-technical transition processes on the sustainability transition?

   The aim is to explore the effects of offshore wind development on the socio-technical transition to understand the interaction between social actors and their context.

3. What is the role of social actors in the processes of socio-technical transition towards a sustainable low carbon electricity system?

The aim is to explore the important role of social actors to shape a new technological system and to change its context.

2.6. Conclusion

This chapter explored theories and literature in socio-technical system transitions and sustainability. It has been evident through reviewing literature that transition theory has been applied to different theoretical and empirical studies, and refined and revisited by researchers. A number of limitations of transition studies have been identified and built into this research.

Taking a constructivist perspective is deemed appropriate for the analysis of change in components of a system individually, however, the characteristics of the whole system will be complex since these ongoing processes will be socially embedded and institutionalised over time. Therefore, transition theory (the MLP) is employed to inform changes at multi levels of a system.

Studies on the socio-technical transition towards sustainability, such as the transition towards a low carbon electricity system in the UK from the dominant fossil based (high carbon) energy system, involve multiple factors and multiple actors. The MLP provides a useful frame to analyse the processes of interactions and alignments between technology and institutions. While the MLP provides broad insights on socio-technical transitions, it neglects the interpretative role of actors in constructing the institutions and shaping the technology, particularly as technology and institutions co-evolve. Although there are academic works around the interactions between technology and institutions, there is an absence of research that includes the interactions of actors as well.

The analytical framework and research questions are proposed to address those limitations and gaps. While the transition scholars argue that change in socio-technical systems occur through interactions of the three levels, taking insights from the development of offshore wind energy within the electricity system, the research shows that interactions are mainly between social groups of actors, technology and institutions. Therefore, the analytical framework illustrates the interactions between these three pillars and the research also takes insights from transition theory, particularly the MLP to have a broad vision of analysis of multiple factors, multiple actors and the three analytical levels. The framework, however, will be conceptualised in chapter 4 along with the analysis of the data collected during the empirical stages of this research.

Chapter 3: Methodology

3.0 Introduction

This chapter justifies the research design of the thesis and explains the methodology applied in this study and the methods used for information which forms the study's analysis. The chapter illuminates the way in which the research aims and objectives are approached in this study and discusses the methodological elements that are important for this study. The main objective of this research is to understand the significant role of the offshore wind system within the process of transition. The research achieves this aim by addressing the research questions:

What are the effects of the socio-technical transition processes on the development of the offshore wind system to transform the electricity system towards a more sustainable configuration?

1. *How do non- technical and technical factors affect the development of the offshore wind system within the UK energy regime?*
2. *How are the transition processes within the energy regime affected by offshore wind development? What are the effects of the interaction between levels in the socio-technical transition processes on sustainability transition?*
3. *What is the role of social actors in the processes of socio-technical transition towards a sustainable low carbon electricity system?*

The first section provides the research design followed by philosophical views of the research inquiry, this chapter then explains the methodology applied in this research and the methods used in the data collection and analysis.

The study is first based on a systematic review of the existing academic literature, using key words such as: socio-technical transitions, sustainability transitions, and electricity system transitions. Then, a snowballing approach for reviewing literature was used due to the complex and multi-dimensional nature of the electricity system and socio-technical transitions studies. A large body of literature with broad perspectives on the topic were found in disciplines including engineering, technology management and sociology. A range of public and government agency reports, including policy and stakeholder documents, were also included in the literature review.

3.1 Research design

The previous chapters discussed the theoretical (Chapter 2) and conceptual (Chapter 1) issues associated with socio-technical transitions and explained the interactions between social actors, institutions and technological change. The proposed research framework (section 2.6) drew from reviewing a wide range of literatures and identifying research gaps, and outlined the key analytical elements that are necessary for socio-technical transition studies. In order to increase knowledge and understanding of the research inquiry, appropriate methods for collecting relevant data and for analysis and interpretation are required (Creswell, 2009). Therefore, the role of this chapter is a bridge between the theoretical and empirical parts of this thesis.

The design of this research required a number of decisions based on the nature of the research problems, the researcher's philosophical stance and the methodology. Therefore, this part draws some of the practical issues connected with applying the research framework to the real world.

The purpose of developing the analytical framework and applying it in the real world is to gain new insights and understandings of the socio-technical transition in the electricity system. This approach draws from a social constructivist philosophical worldview where it is argued that reality is socially constructed through a series of interactions (Berger and Luckmann, 1966). Similarly it is implied in the socio-technical concept, where it is argued that technology (technological change) is shaped by human action through a series of social interactions (such as interpretations). Therefore, technology is socially embedded in its context and its existence depends on human cognition.

As discussed in Chapter 2, new institutional and evolutionary economics, and science and technology studies emphasise the importance of social context in shaping technological change, for example selection environments in strategic niche management studies. Arguably, a system level approach is an appropriate strategy for this study, due to multi dimensionality of socio-technical transition. Because the system approach allows the research framework to include variety of social processes which fulfil the analysis of process of technological change. This analysis requires a broad interpretation including interactions between actors, technology and institutions.

Therefore, the research sought to understand and to discuss how the development of a new technological system is socially constructed.

3.2 Research philosophy

The research philosophy or philosophical paradigm refers to how to view the real world and how to explore the nature of reality and existence (Glesne, 2011, p. 5-6). It shields ontological and epistemological assumptions which *'underpin'* the research design and methods for the analysis in this study (Saunders et al., 2007 p. 101). The philosophical assumptions have affected the research design and implications for the methodology. Philosophical assumptions underpin the research design and the techniques for collecting meaningful data to provide adequate evidence reflect for the research inquiry. The rationale behind the importance of understanding the philosophical assumptions contains three main elements that affect the research process. These elements include: *'clarity'* of the research design, understanding the applicable methods that *'work'* with the research design, and identifying the research process that adapts to the research design and structure (Easterby-Smith et al., 2012, p17).

Since the philosophical assumptions are important to justify the sustainability of the research design and methodology for the analysis, the main focus of this part is to explain the ontological and epistemological assumptions of this study. Ontology refers to the nature of *'reality'*, *'truth'* and *'existence'* of the social world and reflects beliefs about the reality and existence of the world. It considers the knowledge of the reality base on beliefs of what knowledge is considered to be. Epistemology is about the nature of knowledge that informs the research inquiry, which shapes and justifies the methods of inquiring into the reality (Glesne, 2011, Easterby-Smith et al. 2012, Creswell and Plano Clark, 2007).

There are two major contrasting views about the nature of reality of social and physical worlds within the social sciences. Positivism views reality as a single object and from the exterior. In contrast, social constructionism assumes that reality is socially constructed by individuals and the social world is given meanings and made up by people through their actions and interactions towards *'certain'* objects (Easterby-Smith et al., 2012, p21-24 and Creswell, 2013, p.24-25).

Social constructionism refers to a *'process of interaction'* (Creswell, 2013, p.25) in which individuals create a *'shared reality'* that is continuously experienced as objectively truthful and subjectively meaningful (Berger and Luckmann, 1966).

This study is conducted through the lens of social constructionism. The ontological assumption in relation with social constructionism views the world in which socially-constructed realities (social realities) are subjectively interpreted in a certain context setting by individuals' beliefs. In other words, social realities refer to shared beliefs that are institutionalised within society.

Since the understanding and interpreting of phenomena that formed the social world is subjectively shaped through members (actors) of social groups' beliefs, it is important that social constructivist researchers focus on social actors' views, their interpretations of the event and social interactions with each other about the inquiry being studied. The social actors (members of a certain social world- for example electricity system in this study) have multiple interpretations of events through their experiences which leads them to construct diverse meanings and perceptions of the situation through interactions with other members of the social group (Creswell, 2014, P.8). This means that social realities are dependent phenomena and constructed through interactions between social actors of a certain context.

As discussed above, the social interpretations are multiple and diverse and lead researchers to include diverse views being discussed by participants about social phenomena that are socially constructed through their experiences of *'historical and cultural settings'*. So, it is important to rely on the views of social actors (Creswell, 2014, P.8). Therefore, qualitative approaches such as *'open-ended'* interviews (Creswell, 2009, P.8) are commonly employed by constructivist researchers. The qualitative methods enable researchers to access multiple realities of what social actors are *'thinking'* (Easterby- Smith, 2008, P.24) and *'interpreting'* (Creswell, 2009, P.8) of social phenomena.

Socio-technical transition is a socially constructed multi-dimensional phenomenon that can be studied in diverse contexts and from different ontological angles (Geels, 2010). With regard to the creation of knowledge, Hirschman (1986) from the constructivist school believes that social construction inquiry *"is based on a set of fundamental beliefs the scientist has about the nature of reality. In essence, they define what phenomena the* *scientist believes to be knowable, the way in which phenomena may become known, and criteria for evaluating what becomes known."*

According to Creswell (2014, P.8) the researchers' backgrounds and experiences: *"shape their interpretation and they position themselves in the research to acknowledge how their interpretation flows from their personal, cultural and historical experiences."* In relation to this, Hirschman (1986) also indicates: *"research inquiry is a social construction resulting from the subjective interaction between the researcher and the phenomenon. Thus, knowledge is subjectively attained; knowledge is constructed, not discovered."*

While the researcher's background and experience in the energy industry helped her to shape the process of this research, her role as a researcher intended to interpret the perspectives that social groups have about the issues that are being studied. This means participants' interpretations influence the research inquiry. Therefore, an inductive approach was adopted for this study.

The researcher proposes that social constructionism is appropriate and relevant for the study of energy transition which is a socio-technical process constructed by social actors. In this study the focus is on the development of a new technological system with shared characteristics of perspectives and understanding of the processes of transition being experienced by social actors. The development of a technological system, which is constructed through human actions and interactions within the context of energy transition assumes knowledge of the social world. The notion of this knowledge creation within the social context underpins the social constructionist philosophy. The development of a technological system is a socially constructed process which involves social actors' perspectives, so the researcher attempted to gain and record the social actors' perspectives and experience about aspects of socio-technical change in the process of transition. Therefore, social constructionism is deemed appropriate to explore the research questions.

While technology is seen as a *'material culture'* of the social world, the context of technology (institutions) reflects the *'non-material'* in terms of the externalisation of the social world. Similarly, the study of energy transition involves the development of technological systems; for example offshore wind in this study. The offshore wind system contains physical (technology) and non- physical artefacts (institutions) which are socially constructed, since they are created and developed by human actions and interpretations.

The artefacts of a technological system interact with each other so changes in characteristics of a physical or non-physical artefact lead accordingly to alterations in other artefacts' characteristics (Hughes, 1987, P. 45-46). The existence of a technology can only be understood in a certain context that is only real for the social actors who hold it. Moreover, technology and its context only exist and are real to people who hold beliefs that are *'shared'* and have been *'institutionalised'* (Berger and Luckmann, 1966). This means that these socially constructed artefacts are dependent on each other, the existence of one depends on the reality of others. Also, the context of a technological system is socially shaped by social actors through *'regional'* and *'historical'* experiences (P.63) which again indicates that technology is embedded in a specific context that is experienced continuously.

Therefore, the ontological position provides a lens for the study of the sustainable transition and for interactions between social actors, technology and institutions. As mentioned above, there are systematic interactions between technology, institutions and social actors. The existence of one depends on the others; accordingly, development in one influences the others. Because changes in socio-technical systems require institutions to change, this needs changes in social actors' beliefs and their interpretations of the institutions that have been socially constructed. Meanwhile there may be disagreements that occur between social actors which leads to them to *'reproduce and/or modify'* (Geels, 2010) belief systems and cognitive rules. From this ontological position, the interactions between technology, institutions and social actors, which are taken as the entry point for the analysis of this research, contribute to the research inquiry in relation to the socio-technical transition towards sustainability.

As explained above, the implications of the ontology should be able to address specific phenomenon in a certain context. The socio-technical transition theories that are employed in this research embody the ontological assumptions in relation to sustainable energy transition. These theories highlight multiple views of transition; for instance, the importance of the role of social actors in interpreting the interactions of the three analytical levels (niche, regime, and the landscape) towards sustainable energy transition. The socio-technical regime consists of incumbent rules (cognitive and regulative rules) which are given meaning by social actors.

In this study, the researcher attempts to focus on sense-making of data by which social actors interpret the development of a socio-technical system (offshore wind system) through *'interactive mechanisms'.*

These interactive mechanisms consist of conversations, debates, negotiations, and learning processes which are socially constructed. Learning processes include determination of performance towards improvement as well as cognitive learning which emphasises beliefs, actions and interactions which are interpreted by social actors. Situated learning processes within the context of the technological system development assumes that knowledge is constructed through human actions and interactions and also that this knowledge is continuously evolving. However, social actors may imply different interpretations and perceptions of the technological change within their context because learning processes are influenced by their experiences, beliefs and interpretations (Geels, 2010).

Social Construction of Technology (SCOT) theory, which is a socially constructed phenomenon, is employed in this research. According to the SCOT, development of technology is a continuous process until relevant social groups within their context reach social agreement through the interpretive flexibility of technology (Pinch and Bijker, 1987). The underlying assumption for this study is that the social actors, technology and its context are related to each other and there are systematic interactions between them. Technology is shaped, designed and developed by human actions and is dependent on its context. The *'existence'* of technology and embeddedness in its context depends on human *'cognition'*, *'beliefs'* and *'interpretation'* which are shared and institutionalised socially.

Interpretivism is deemed appropriate to fulfil the epistemological assumption where the research intends to describe, interpret, record, and analyse aspects of the social world thorough interpretations of specific events or processes from individuals' experience and understandings point of views (King and Harrocks, 2010, P.11). Similarly, in this research, in relation with the development of the offshore wind system, the focus is on participants' perspectives of how they interpret their understandings and experiences of being part of the system. For example, with regards to the research questions and objectives of this thesis, the aim is to understand an aspect of energy transition from social actors' perspectives, where the focus is on the development of the offshore wind system within the process of electricity system change.

To make the research aim achievable, social actors' perspectives about the process of transition need to be *'captured'* (King and Horrocks, 2010, p.7), recorded, interpreted, and analysed.

The focus on the social actors' perspectives and interpretations of their related experiences of the situation (offshore wind system development) and the social actions and interactions with their context qualifies interpretivism as an appropriate basis for conducting this study. Therefore, interpretivism emerged as a preferred choice of epistemological assumption to fulfil the research objectives.

Blaikie (1993) believes that interpretivism *"requires an understanding of the social world which people have constructed and which they reproduce through their continuing activities."* (P.36). Interpretivism is a broad approach; however, King and Harrocks (2010) summarise it as *"how the social world is experienced and understood"* (P.11). Since, the focus of the interpretivism epistemology is on individuals' perspectives and interpretations about their lived social world, qualitative interviewing is a favourite method to understand their experiences (King and Harrocks, 2010, P. 11).

3.3 Methodology

Technology is shaped, designed and developed by human actions and is dependent on its context, which is also socially constructed and institutionalised by human actors through their interactions and continuous creation experiences. In this study, the context of technology, such as policy, science, research, market etc., is known collectively as institutions. Also, the term *'socio-technical system'* refers to both technology and institutions; therefore, the research methodology considers offshore wind as a socio-technological system and so uses the term *'offshore wind system'* to include both components where necessary.

This study sets out to explore the effects of socio-technical change to develop a low carbon technological system (the development of offshore wind energy) on the transition process. The main objective of this research is to understand the important role of the offshore wind system within the process of transition. To achieve this aim, understanding of the technological and institutional characteristics of the offshore wind system is vital. This requires an appropriate systematic analysis in the field of energy transition studies, since a transition to a low carbon energy system uncovers *'systematic* *interaction'* (Hughes, 1987, p. 45) between key actors, and institutions and technology within the process as well as interactions between the current socio-technical regime, macro factors at the landscape level and technological development at the niche level.

The primary focus of this study is on the East Anglian coast for development of offshore wind projects. However, the study does span a wide range of factors where appropriate, and national and European level aspects of energy policy are also included to analyse interactions more broadly. The aim is to place regional particularities in a national context, since energy policy, energy infrastructure (consent and planning legislation), the electricity market, and grid transmission are centralised at a national level in the UK. The emphasis of this research is on the interactions of technology and institutional factors and the role of key social actors within the electricity system. So, empirically the focus is on the UK, but particularly East Anglia due to the geographical and historical development of offshore energy projects, including oil & gas and offshore wind, in this particular region. This aim is conceptualised in the model in Figure 3.1 (section 3.4.2.4).

Therefore, the research aims to understand how relevant social actors characterise the offshore wind system. To achieve this aim, the study explores how relevant social actors interpret the non-technical and technical factors that affect the development of the offshore wind system within the process of transition towards a more sustainable electricity system. The relevant social groups refer to both organised and non-organised groups of social actors who share the same set of meanings for an object, so existence of a problem depends on how they define it within their context (Pinch and Bijker, 1987, P.23). This means that the relevant social actors are from a particular context and aim to achieve the same overall goals. In this study, the relevant social actors share a common goal which is the development of the offshore wind system (section 3.4.1). However, the social actors' interpretations of the development of the socially constructed offshore wind system might be multiple and diverse.

The development of offshore wind system is a socio-technical process that is occurring within the current energy regime. This current regime consists of fossil fuel based power plants, and established firms which are a major part of the energy mix, alongside nuclear power plants and renewables (off and onshore wind, solar, tidal, hydropower, and biomass). This study attempts to understand the effect of offshore wind development on the electricity system transition.

The current energy regime consists of an established system of incumbent technology, firms, rules, and markets which offshore wind system will need to compete with. To understand the process of transition within the electricity system, this research employs the MLP.

In line with the MLP on energy transition towards sustainability, the role of actors in the process is vital. Since the social actors are embedded in their context, their perspectives and defined problems are also considered to be embedded within the context. The climate change agenda and economic conditions represent the landscape level within the MLP, whilst the incumbent energy industry, regulative and cognitive rules within the electricity system are at the regime level, and the development of offshore wind system is at the niche level.

The research methodology refers to the approach that underpins the research. The aim of research approach is to reflect the situation being studied and to consider the researcher's opinion of the world (Blaxter et al. 2010, P.59). Since constructionist researchers are concerned with understanding the socially constructed realities interpreted by individuals about the situation; therefore, based on a philosophical view of the knowledge that is to be studied and in order to fulfil the research objectives, a qualitative methodology is deemed appropriate for this thesis. According to Blaxter et al. (2010): *"the distinction between understanding and explaining underlines that (often exaggerated) between qualitative and quantitative research approaches."*

Qualitative research involves a set of interpretive naturalistic approaches that enable researchers to study realities and to interpret socially constructed phenomena from natural settings that are given meanings by individuals (Denzin and Lincoln, 2008, P.4). Interpretive epistemological assumptions of constructionism also emphasise the role of language in the interpretation of reality that is experienced by social actors. Using language and conversation (Blaxter et al. 2011, P.193 and Kvale and Brinkmann, 2009, P.1&7) enables individuals to share their experiences, perspectives and interpretations (understandings and meanings) of socially constructed realities. Blaikie (1993) states: *"the social researcher enters the everyday social world in order to grasp the socially constructed meanings, and then reconstructs these meanings into social scientific language"* (P.96).

The qualitative interviewing method aims to capture and to record multiple aspects of the individuals' social world where *'knowledge is constructed'* (King and Harrocks, 2010, P. 7 and Kvale and Brinkmann, 2009, P.1-2&30). Therefore, qualitative interviewing provides a path to uncover the *'inaccessible knowledge'* (King and Harrocks, 2010, P. 18, 22). The knowledge that is constructed through qualitative interviewing reflects the reality experienced by social actors in their context. So it is a useful method for collecting data that are not accessible by using other techniques (Blaxter et al., 2011, P.193). This method is suitable to gain insights from organisational actors include managers and employees through discovering their perspectives, perceptions and opinions (Easterby- Smith et al. 2012, P.126).

Therefore, due to the nature of the research aim, it is important to include the views of influential actors who are in principle decision making positions (section 3.3.1.1). This provides additional information to give a broad understanding as to how the development of offshore wind system influences the UK energy transition towards a low carbon electricity system. The qualitative interviewing method is employed in this study because there are a lot of ongoing debates surrounding the importance of increasing the share of renewables to tackle climate change and emissions which makes the development of offshore wind system rather politicised and subjective. Moreover, the perspectives of the relevant social actors are important to understand since their views are informed by multiple interrelated factors which are systematically significant to explore.

The qualitative interviewing method enables researchers to modify the questions depending on participants' positions, experiences and responses and to change the questions to uncover new concepts that emerge from conversations (Easterby- Smith et al. 2012, P.126-7). The format of interviews in this study was structured to ensure a broad coverage of perspectives and to allow emergent themes to be explored. For example, in this research, the first interview question started with asking the participants to describe their role and responsibility within their organisation. This question was designed to explore the respondents' experience and their response then influenced the subsequent questions.

Qualitative interview formats vary depending on the degree of structure. Formalised and structured interviews require researchers to prepare sets of questions which are carefully piloted, refined and validated, while less-structured interviews enable researchers to explore some questions further or to discard questions (Easterby- Smith et al. 2012, P.127). Therefore, by using less-structured interviews, researchers are more flexible in terms of exploring further and deeper into uneven themes that emerge. Similarly, during data collection for this research, a new policy instrument was introduced, called the *'Contract for Difference'*, which impacted many aspects of energy transition and participants' perspectives. Therefore, the researcher included additional questions relate to this issue in the interviews.

Although researchers by using less-structured interviews can be more flexible to develop specific themes, they are encouraged to follow an overall interview framework to ensure that all issues are covered in the interview sessions (Easterby- Smith et al. 2012, P.127-8).

A semi-structured interviewing method was used in this research. This decision was made because the research objectives aimed to increase knowledge about the effect of the development of the offshore wind system. Furthermore, the research ontology suggests that more open-ended interview questions bring opportunity for researchers to collect more insights and opinions from participants towards the research question. The role of constructivist researchers in relation to the knowledge that is being researched reflects the research questions, the structure of interview and methods of analysis (King and Harrocks, 2010, P.22-3). In this research, the researcher has prior understanding about renewable energy research and experience in the energy industry. This practical background and experience, along with a thorough review of the literature helped her to enter the fieldwork with key questions (Easterby- Smith et al. 2012, P.127) to find information in those areas that remained under researched.

3.4 Method of collecting data

This section describes the method adopted to collect data for the qualitative research into the socio-technical transition towards a more sustainable electricity system. The data for this study were collected from 41 semi-structured interviews which collected between June 2014 and August 2015, field notes from 12 industry and government conferences, workshops and networking events and 17 documents and reports. Therefore, the research has taken advantage of a triangulation method for collecting data. This method provided a sufficient level of *"using multiple perceptions to clarify meaning, verifying the repeatability of an observation or interpretation"* (Stake, 2005, P.454) for this research.

3.4.1 Semi-structured interview

The data for this research were collected from 41 semi-structured interviews. The first three interviews were piloted between June and September 2014. Then between September 2014 and August 2015, semi-structured interviews were conducted within the East Anglia region and in the UK with relevant actors. Some of the interviews were conducted face-to-face, some by telephone or Skype. The interviews lasted between 20 and 120 minutes.

The pilot study was carried out with contacts from the three main types of energy organisation which includes: the national energy regulator, a regional industry and skills association for the energy supply chain, and a local authority. The pilot study trialled the preliminary question design and the initial contact approach. The pilot study resulted in some modification of the questions to minimise the effect of key words in the questions and to allow participants to explain their views more widely. Also, the length and number of questions were reduced to allow them to be answered in a given time slot and the issues that needed to be covered. However, interview questions were continuously improved during the data collection stage, in order to ensure that the fieldwork generated a high volume and quality of data.

3.4.1.1 Participant selection

The research aim is to include the most *'influential actors'* (Pinch and Bijker, 1987, P.23 & 28) who are involved in the development of the offshore wind system in the East of England coastal location and in the UK. It is not the aim to select a large number of the population.

It was more important for the study to ensure a reasonable range of key actors were included in order to record and capture diverse perspectives. To achieve this aim, the researcher categorised the key social groups involved in the offshore wind sector in order to select participants. The four major groups identified were:

- International, national and regional policy groups, authorities and government agencies
- The supply chain including developers, manufacturers etc.
- Research groups: energy and innovation, academia
- Energy and business organisations

In relation to relevant social groups, Pinch and Bijker (1987) believe that: *"the key requirement is that all members of a certain social group share the same set of meanings, attached to a specific artifact."* Creswell (2013) states: *"the concept of purposeful sampling is used in qualitative research. This means that the inquirer selects individuals and sites for study because they can purposefully inform an understanding of the research problem and central phenomenon in the study"* (P.156).

Therefore, in line with Pinch and Bijker's suggestion, the *'influential actors'* were purposively selected from these four groups in this research. This allowed a wide range of perspectives to be captured and avoided the selection of organisations and actors biased with similar perspectives. Although the majority of actors were selected from East Anglian organisations, where the research required, participants were included from the wider context (national and EU level) to maintain the achievement of a wide range of views being collected about the research questions and objectives. Therefore, 41 interviews were sufficient to enable the researcher to develop meaningful themes and robust interpretations (Guest et al, 2006).

Offshore wind is a relatively young industry and has been built upon other offshore sectors' (such as oil and gas) experiences and technologies. Although the offshore wind sector is developing, it still is part of the energy mix which is dominated by fossil fuel base energy sectors. Many of the participants therefore had experience of a range of offshore sectors and this brought additional advantages for the research because the experience of multiple sectors reduced the bias towards a single energy system. Their role over time had been split between the niche level (offshore wind sector) and the regime level (oil or gas energy sector) and therefore included diverse opinions which enriched the data collected for this research.

Table 3.1 lists the interviews, including the interviewees' codes which are used in Chapter 4 and 5, and the participants' positions. Because some participants have multiple roles and responsibilities, the table shows more positions than the number of interviewees suggests.

The researcher employed the notion of theoretical saturation for the research strategy, so when the outcomes of the interviews about the topic being studied failed to generate new themes and information, further data collection was discontinued.

Table 3. 1 Research Participants

Code	Category	Position
En.L 1	Regional Energy Organisation	CEO
En.L 2	"	Business Development Lead
En.L 3	"	Corporate Director with responsibility for Energy
En.L 4	"	Economic Development Officer
En.L 5	"	Executive Director
En.L 6	"	Inward Investment Director
En.L 7	''	Inward Investment Director
En.N 1	National Energy Organisation	Associate Director
En.N 2	"	Associate
En.N 3	"	Executive Management, Innovation & Research Director
En.N4	"	Head of grow offshore wind
En.N5	"	Market Insight Manager
En.N6	"	Head of Offshore Commercial & Asset Management
P.L 1	Local Policy	County Councillor
P.L 2	"	Economic Development Officer
P.L 3	"	Principal Service Manager Economic Regeneration
P.L 4	"	Corporate Director
P.L 5	"	Chair of Green Economy Path Finder
P.L 6	"	Inward Investment Manager
P.N 1	National Regulatory	Associate Director
P.N 2	"	Offshore Wind Development Manager
P.N 3	"	Strategy and Government Affairs
P.N4	"	Programme Manager Technology & Supply Chain
P.N5	"	Market Insight Manager, Market Intelligence
I.P1	International Policy	Head of Cabinet European Commissioner for Climate Action
I.P2	"	Policy officer
E.L 1	Local Economy Growth	Corporate Director
E.L 2	"	Economic Development Officer
E.L 3	"	Principal Service Manager Economic Regeneration
E.L 4	"	Business Growth Manager
C.L 1	Regional Business Growth and Consultancy	Director
C.L 2	"	Business Development Lead
C.L 3	"	Business Growth Manager
C.L 4	"	CEO
C.L 5	"	Director
C.L 6	"	Managing Director
C.L 7	"	Business Developer
C.N 1	National	Associate

Continue on next page

Table 3.1 continued.

Code	Category		Position
SC 1 **SC 2** **SC 3** **SC 4** **SC 5** **SC 6** **SC 7** **SC 8** **SC 9** **SC 10** **SC11** **SC12** **SC13**	Offshore Wind Supply Chain:	Seabed	Commercial Director/ Head of Renewables group
		Vessel,Foundation,Construction	HR/Crewing Manager
		Crew Vessels	Commercial Manager
		Marine	Head of Sustainable Energy
		Turbine	Director
			Offshore Managing Director
		Developer	East Anglia ONE Managing Director
			Head of Strategy Wind power & Technology
			Head of Investment & Asset Management for offshore wind
		Operator	General Manager
		Owner	Vice president, owner of Sheringham Shoal
		Supplier	Commercial Manager
		Cables	Global Sales Manager, Global Service
			Technical Sales Manager, Subsea Power Cable
SC14		Engineering, Service	Business Development Coordinator
M.L1	Energy Market Analyst		Principal Consultant
M.L2	Energy Market Analyst		Analyst
M.L3	Energy Market Analyst		Business Development Coordinator
M.N	Energy Market Analyst		The Renewable Energy Financial Advisor, Director
	Energy Policy Analyst		Green Economy Path Finder
EG	Engineer- OWMS System		OWMS Support Engineer
AC 1	Academic and research		Board Director
AC 2	"		Academic Professor

Note: some participants fall into more than one category and therefore the total number illustrated in Table 3.1 is greater than 41 participants.

3.4.1.2 Participant engagement and trust

A set of ten questions were *'shared'* with participants before the interview took place (Marshal and Rossman, 2011, P.144). Sharing interview questions was a successful strategy in this research which fulfilled two distinct purposes. Firstly, this strategy was helpful to increase the level of participants' engagement to the topic; also, it allowed participants to prepare their contributions, which resulted in more effective conversations and a natural flow during interviews. Secondly, this strategy was important to build *'trust'* (Easterby-Smith et al. 2011. P.136).

The prior communication enabled participants to verify the identity of the researcher and purpose of research (participants were ensured that the purpose of the interview was to understand their perspectives). It also ensured the researcher that interviewees provided thoughtful insights and information rather than ad hoc brain storming. Overall, it increased the level of trust between the researcher and participants.

Building good communication and trust was key in this research, since participants shared information with the researcher regarding upcoming events and conferences, the latest released reports and documents, and introduced her to further contacts and relevant organisations.

3.4.1.3 Obtaining access

Obtaining access with regards to data collection is an issue that Easterby-Smith et al. (2011) identify (P.126). This issue affected the process of conducting this research. At the beginning of the fieldwork, access to participants was a slow process. This issue was solved using a number of methods. The first two interviews were secured through the researcher's existing network. The third contact as part of the pilot study was identified through a public interview released in the local press. Reading the local press and accessing online social networks, such as LinkedIn and Twitter, were also helpful to identify key actors from the region as an entry point to the network.

The snowball method was mainly used for collecting data in this research. Existing contacts were asked to identify further key actors involved in the area under research. However, this process was discontinued when the same participants who had already been interviewed were being suggested.

Networking and meeting attendance were another useful method for obtaining access. These networking events served multiple purposes. The researcher increased her contacts by attending different networking events, workshops and conferences regionally and nationally. This method assisted her to secure further contacts for interviews, and then snowballing was also used with new contacts. Moreover, networking and attendance at different events facilitated trust and helped to develop good communication with participants which helped for the actual interviews.

3.4.1.4 Recording, Transcribing and Ethics

All interviews were recorded, using an audio recorder machine and the researcher took brief notes. The participants were provided with a consent form prior to the interview sessions, to explain the purpose of the research, to inform them about the confidentiality of the information they would provide and that any comments would be anonymous and only published for academic purposes.

Three participants expressed their agreement by email regarding the interview being recorded. One of the participants did not sign the consent form and therefore according to the University of East Anglia's ethics policy, the researcher did not use any information regarding that interview. The consent forms were signed by participants at the beginning of the interview. The telephone interviewees emailed the signed forms to the researcher, either way, they signed the forms at the upcoming networking events.

The ethical issues were carefully considered by the researcher. All participants were informed in a briefing about the topic prior to the interview and asked to consent being interviewed (King and Harrocks, 2010, P.110). Anonymity of the participants was highly protected during the whole process of this research. Each interviewee was assigned a code to make reference to their quotes in the findings and analysis chapter, so that they cannot be individually identified. Furthermore, all audio tapes and transcripts were kept confidential and stored in the researcher's personal computer at her office where only the researcher could access them. All notes from the interviews were also stored in a locker in the researcher's workplace. This was in accordance with guidelines set by the University of East Anglia.

Some of the interviews were transcribed professionally, and a confidentiality agreement was in place for this. The researcher validated the transcripts comparing with the audio. The researcher used NVivo slow mode for transcribing some interviews.

The researcher offered participants a copy of their interview transcript. Two interviewees asked for the transcripts; therefore, the researcher ensured them that the information of the interviews will only be used once they agreed the verbatim transcripts.

3.4.1.5 Location

The location of the interview was also considered to be important in the process of the interviews. The interviews were conducted on a one-to-one basis. For those interviews that took place face-to-face, the researcher travelled to the participant's office at their organisation; however, three interviews took place in the researcher's workplace. So the researcher booked meeting rooms to fulfil the confidentiality purpose.

The telephone interviews also took place in the meeting rooms at the researcher's work place. This was important especially for the participants who interviewed over the phone and skype to maintain trust and confidentiality in terms of their voice being heard only by the researcher. For the telephone interviews, the researcher called participants at the agreed time, explained the ethics and consent, and then asked for permission to set the phone on speaker to record their voice using the audio recorder.

3.4.2 Attending meetings

Attendance at twelve networking and workshops events, exhibitions and conferences was an important aspect of the fieldwork. These events fulfilled two purposes. Firstly, these events provided the researcher with up-to-date information about multiple issues regarding the development of offshore wind; for example, policy changes and developments in relation to offshore wind from multiple perspectives. This also provided a platform for understanding interactions between social groups. Secondly, it was an opportunity for the researcher to become a *'recognised actor'* within the network which helped to obtain access to key social actors within the sector. The events attended with dates are listed in Table 3.2.

Field work notes were taken at the events including presentations, facts and figures, and key discussions. These were used as part of the data analysis (section 3.4).

Table 3. 2 List of event attendance

Event	Details	Date
Regional membership focus group and networking	8 hours	30 September 2014
Regional networking: Skills for Energy	4 hours	30 January 2015
The Conference for Offshore Energy: Southern North Sea 2015, The Sea of Opportunity	14 hours	4-5 March 2015
The Southern North Sea 2015: Exhibition, meet the buyers	8 hours	4-5 March 2015
Global Offshore Wind 2015 Conference, Renewable UK	16 hours	24-25 June 2015
Global Offshore Wind 2015 Exhibition, meet the supply chain	8 hours	24-25 June 2015
Regional-national workshop: Challenges and Opportunities in the Offshore Energy Sector	8 hours	16 July 2015
East Anglia ONE Supply Chain Update and Networking Event	8 hours	16 July 2015
EEEGr Awards 2015	8 hours	16 July 2015
ECOWinds Final Conference	26 hours	28-30 September 2015
International conference series: the US conference	2 hours	20 October 2015
Offshore Wind Week- East Anglia Event- Offshore Wind Works	10 hours	19 November 2015

3.5 Data analysis

This section elaborates the techniques implemented to analyse the data collected from the interviews. In this study, the researcher commenced preliminary analysis in parallel with the data collection phase. The early stage analysis assisted the researcher to improve and to refine the interview questions as discussed in section 3.3.1. Furthermore, this strategy was useful to ensure that the topic being studied was covered; therefore, the researcher was able to validate that the fieldwork generated high volume of the data in terms of the length and depth. The fieldwork data collection stage was a *'learning process'* for the researcher, providing opportunities to enhance her understanding of the concept distinct from the literature and to overcome the research issues.

The context for the analysis of this thesis is provided by data-driven (inductive) and analytical framework approaches. Thematic analysis was employed to analyse data in this research. To answer the first research question, themes were generated from the data inductively. Therefore, the research model emerged from the analysis (Figure 3.1). Braun and Clarke (2006) explain thematic analysis by defining: *"a theme captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set"* (P.82).

The nature of the second research question required broad sets of data to be analysed, since it aims to understand the interactions between social actors and the context within the transition processes. Therefore, to ensure the data collected was structured around the research question and fulfilled the research objectives, a manageable format was adopted to synthesise and condense the data. Based on the literature review in Chapter 2, scholars have identified distinct schools to study transition processes. In this research, to analyse data in response to the second research question, the MLP analytical framework was adopted from Geels' school.

The MLP framework is structured around the niche level, the socio-technical regime and the landscape. There are processes within each level and the interplay between these levels that need to be understood in order to study transition. For the second research question, the researcher used inductive themes from the first research question as a platform to analyse the data. The third research question; however, attempted to build a coherent argument of overall findings by highlighting the significant role of social groups within the context.

In doing so, the researcher used inductive themes that were emerged from the data. The following sections explain the process of data analysis and technique that were used in this research.

3.5.1 Data analysis process and technique

The interviews were transcribed electronically stored in the researcher's workplace computer. All of the interview information including audio and transcript files, participants' and companies' information were stored in folders separately. Each folder's name referred to the company's name. Also, each participant, based on their category, was given a code as illustrated in Table 3.1. These classifications made the dataset organised and tidy. The audio tapes were often played during the process of transcribing, validating and also analysing the data.

At the start of the analysis process NVivo 10 analysis software was used to assist in data management in terms of classification and organisation. NVivo is computer software designed to assist qualitative researchers for the analysis of large text based data sets (Bazeley, 2007, P.2-3). NVivo is a useful tool to assist researchers in breaking down the data into groupings and searching for relationships within the data. However, due to the multidisciplinary nature of social actors as explained in section 3.3.1.1 (some of social actors belong to several categories) in this study, the line between social groups was disbanded. Moreover, due to the multiple actors' categories, the interview questions were slightly tailored into their expertise to maximise capturing data. Based on this argument, NVivo was unable to provide the researcher with a wide horizon to see individual opinions and to duplicate them where possible, so the decision was made at an early stage of analysis to use a tactile method. Therefore, a manual coding technique was subsequently used for this research.

The researcher, first, analysed first four interviews to generate initial (global) codes that emerged from the data. Second, the researcher inserted a table, using Microsoft Word with four columns: code refers to issues that emerged from the interview data, theme explains the importance of the code in relation to the data, quote refers to the participants' verbatim responses relating to the initial theme, and source represents each participant's code, as illustrated in Table 3.1.

Then the outcomes of the analysis of each interview were imported into the analysis table. During the analysis phase, the codes were broken down into more focused issues reflecting the research questions.

3.5.2 Thematic analysis

Thematic analysis is one of the methods to analyse *'qualitative'* interviews from participants' *'experiences'* and perspectives. It assists qualitative researchers to organise a wide range of information in a systematic approach so as to describe data sets in rich details and to interpret multiple aspects of the topic being studied. A thematic analysis method is useful to identify, analyse and report themes (Aronson, 1995, Braun and Clarke, 2006, Boyatzis, 1998, P. 4-6). In this research, to analyse the qualitative interview data, the researcher employed thematic analysis.

Braun and Clarke (2006) identify two main forms of thematic analysis: inductive (data-driven) and theoretical (deductive). They explain: *"an inductive approach means the themes identified are strongly linked to the data themselves"* (P. 83). They also describe: *"a theoretical thematic analysis would tend to be driven by the researcher's theoretical or analytical interest in the area, and it thus more explicitly analyst-driven"* (P.84). As explained in section 4.4 this research used both inductive and deductive methods. Aronson (1995) and Braun and Clarke (2006) provide a practical step-by-step procedure for performing thematic analysis on qualitative interview data which the researcher adjusted as explained in sections 3.4.2.1-6.

3.5.2.1 Data familiarisation

The researcher completed the data cleaning process when she transcribed, validated the transcripts and prepared the information for the analysis. In order to build a rich data set and to reduce basis, the researcher listened to the interview's audio tapes while re-reading the transcript (Braun and Clarke, 2006, P.87). It was a useful technique to identify participants' points that they emphasised more by their voice, where the written data was unable to show verbal emphasis. Once the researcher was familiar with the data, she started to identify initial codes that emerged from each interview. However, coding was an ongoing process which developed (Braun and Clarke, 2006, P.87) and was refined within the analysis process.

3.5.2.2 Identifying initial codes

During the fieldwork, 41 interviews, totalling 1602 minutes were conducted and 17 documents of 495 Pages were reviewed and analysed. In addition to these, 12 conferences and networking of 104 hours was attended. To keep the data organised and easy available, it needed to be summarised. Boschmann (2011) states that coding is *"reducing respondent's words into smaller meaningful ideas by linking to specific concepts"* (P. 676). In this phase, the coding process was shaped after the researcher familiarised herself with the data and started generating global codes (such as cost, policy and market) from the first four transcripts. Boyatzis (1998) explains*: "the unit of coding is the most basic segment, or element, of the raw data or information that can be assessed in a meaningful way regarding the phenomena"* (P.63).

At this stage, the researcher identified global codes based on the issues that the first four participants pointed out about the subject being studied within the interview conversation. Then, four more interview transcripts were selected, one from each of the four groups of participants to generate further codes and to compare with those global codes. This method helped to organise the data for quick availability and retrieval.

At this stage, the researcher analysed each interview transcript separately to generate initial codes, to develop themes and to reference quotes. Therefore, the researcher organised the identified codes into meaningful groups of codes and themes in relation with the topic being researched. During the analysis process some themes were broken down into sub-themes which reflected the research questions. Because the data analysis in this research was dominantly inductive, it was important to code and theme all actual data (Braun and Clarke, 2006, P.89) and import them into findings and analysis table (Appendix 4). The table illustrates some codes, themes and quotes to provide with a sample that outlines the link between the data collected, themes and sub-themes.

4.5.2.3 Developing themes

In this phase, the researcher classified patterns that were enriched by data from the interview transcripts into sub-themes. Themes were identified as combined pieces of ideas, perceptions and experiences that emerged from the interview conversations. The researcher then combined and classified these pieces of data collectively to map participants' perspectives into a coherent and meaningful manner (Aronson, 1995).

The researcher reviewed themes and sub-themes to confirm the consistency between themes and codes in relation to the data being maintained. The researcher followed the same structure to code and theme the rest of the transcripts. In this stage, the researcher included the rest of the data set into the identified themes; however, within the process some new themes emerged from the data. These themes were then ready to interpret.

The analysis of the data in this research is based on emerging themes from the data and identified themes from the analytical framework. Both the emergent and theoretically developed themes emerged from the interview transcripts which were combined and classified into a coherent map of the reality interpreted by participants during the interview sessions. In this stage, the researcher determined the concept of themes that captured data. It was appeared that sub-themes emerged from the data in which large themes were broken down into more structured themes. So the more data were attached with sub-themes in relation to each theme.

To obtain a comprehensive map of the data from emergent and theoretically developed themes, the researcher described themes based on the data and in relation to the research questions. At this stage, the data set was built and prepared for writing-up.

3.5.2.4 Building arguments

In this phase, the aim was to form and present a coherent argument based on logic linked with the research questions. This was achieved by selecting emergent themes extracted from data in relation with the first research question. The findings showed that there was a systematic interaction between technological system development, institutions and the social actors, then a model to describe this relation emerged (Figure 2.4).

In order to explain the interactions of these elements and the wider context (for example regime actors and energy firms) deductive themes in relation with the MLP were used. This section was prepared to answer the second research question. The findings suggested that the selection of social groups which captured diverse perspectives of issues surrounding the development of offshore wind system linked with the third research questions to explain the important shared belief system.

3.6 Analysis of documents

The section 3.3.1 explained the process of collecting data from the semi-structured interviews. In section 3.3.2; however, the value of attending industry conferences, meetings and events was outlined. Both data from interviews and field notes were important for this research as explained. This section details the third source of data which was used for this research. In line with field notes and interview data, the research analysed seventeen documents published by the government and sectoral organisations. These documents include government and policy related documents, reports and statistics that were relevant to the research questions and objectives and development of the offshore wind system.

The analysis of documents provided further information to the research regarding the key debates around offshore wind development. Also, document analysis provided an overview to map the energy policy landscape. However, the data from the documents were interpreted as the government and policy makers' perspectives. Each document, similar to participant's category, was given a code as illustrates in Table 3.3. These documents were analysed in the same way as the interview transcripts; but, deductively using the inductive themes from the interview data for extracting further information. Therefore, the perspectives were recorded as human actors' perspectives. This analysis combined with the data was necessary in terms of policy decision analysis. The documents were used in this thesis, have been taken from validated government webpages and also the validation was confirmed by participants and participants during interview sessions referred to them.

Table 3. 3 Document analysis

Code	Document	Organisation	Date	Page
D1	Offshore Wind Cost Reduction Pathways Study	The Crown Estate	May 2012	88
D2	Cost reduction Monitoring Framework, Summary Report to the Offshore Wind Programme Board	Catapult	February 2015	20
D3	Technology Innovation Needs Assessment (TINA) Offshore Wind Power Summary Report	Carbon Trust	February 2012	18
D4	Offshore Wind: Delivering More for Less	BVG Associates	July 2015	13
D5	Generating Energy and Prosperity: Economic Impact Study of the offshore renewable energy industry in the UK	Catapult	March 2014	16
D6	Building Offshore wind in England	CORE	No date	40
D7	The UK Offshore Wind Supply Chain: a review of opportunities and barriers	The Crown Estate	November 2014	49
D8	UK Offshore Wind: Opportunity for trade and investment	UK Trade and Investment (UKTI)	June 2015	44
D9	UK Offshore Wind Supply Chain: Capabilities and Opportunities	BVG Associates	July 2014	73
D10	Electricity Market Reform- Contract for Difference: Contract and Allocation Overview	DECC	August 2013	33
D11	Investing in Renewable Technology- CfD contract terms and strike prices	DECC	December 2013	12
D12	UK Energy Statistics, 2015 & Q4 2015	DECC	March 2016	16
D13	Renewable Electricity Capacity and Generation	DECC	March 2016	1
D14	Renewables	DECC	March 2016	7
D15	Energy and infrastructure key facts 2015-16: UK Offshore Wind	The Crown Estate	No date	5
D16	What next for UK auctions of renewable Contracts for Difference?	Frontier Economics	March 2015	8
D17	Towards Round 3: Building the Offshore Wind Supply Chain	BVG Associates	No date	40

3.7 Chapter summary

The chapter explained the research ontology drawing on the social constructionism philosophical paradigm that affected the way the research has been conducted. Because the researcher does not seek to find a single answer, a qualitative approach has been applied to this research which displays the perspectives of the influential actors selected from the four social groups and draws conclusion from those accounts. The chapter introduced the qualitative methodology applied to this research and it outlined the methods used to collect information and to analyse the data. The chapter explained the semi-structured interview format that was used to collect the data, along with the field notes from networking events to develop a broad understanding of the research area. Further to these sources of data, government and societal documents were also included in this research. The thematic analysis of data were used both inductive and deductive approaches.

Chapter 4: Findings and Analysis

4.0 Introduction

The study sets out to explore the effects of socio-technical change on the development of offshore wind system within the transition process towards a more sustainable and low carbon electricity system. It is evident that as offshore wind system becomes progressively a key part of the UK energy mix, it will play an important role in the UK transition towards a low carbon energy future. The main objective of this research is to understand the role of the offshore wind energy sector within the processes of transition. Therefore, the technical and institutional characteristics of the offshore wind sector require an appropriate systematic analysis in the field of energy transition study, since a transition to a low carbon energy system uncovers *'systematic interaction'* (Hughes, 1987, P. 45) between key actors, institutions and technology within the processes as well as interaction between the current socio-technical regime, macro factors at the landscape and niche development levels.

The findings chapter reveals the outcomes of the semi-structured interviews and discussions that were conducted with a diverse set of 41 key actors consisting of principal leading and decision making positions from multiple key domains of the offshore wind energy sector. Due to the nature of the research aim, it is acknowledged to include the most *'influential actors'* (Pinch and Bijker, 2012, P.23 & 28) accounts involved in the development of offshore wind energy in the East of England coastal location and in the UK.

Because the research interest is to explore the key actors' *'perspectives'* (Pinch and Bijker, 2012, p.22) and to understand the role they play in the processes of the development of offshore wind energy, the actors have been selected from leading positions within key regional energy organisations, principal decision making energy businesses, local authorities, and key leading offshore wind supply chain within the region. However, to have a broad understanding of key actors' perspectives responding to policy related questions and to avoid the selection of organisations and actors being biased with similar perspectives; where the research required, actors in this particular field were also included from the wider context: supply chain, energy organisations, energy trade organisations, energy businesses, energy market analysts and energy policy analysts, energy regulatory bodies, academia, and the European Commission between June 2014 and August 2015 (Chapter 3, section 3.4.1.1 and Table 3.1). Also, field notes from 12 industry and government conferences, workshops and networking events (Table 3.2) and 17 government documents and reports (Table 3.4) are analysed in this chapter.

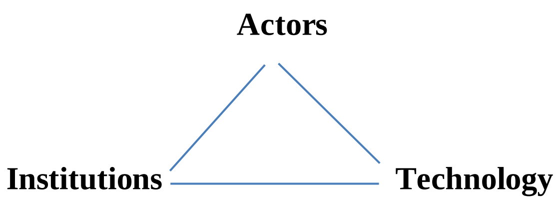
The data analysis reveals the effects of factors that influence the development of offshore wind system and the interaction between the elements of the system in its context while the interactions of multiple levels (niche, regime and landscape) are also included. Technology is shape through human actions, therefore, technology is embedded in its social context (Bijker 1986), it is then argued that human actions can also change the context to develop a new socio-technical system to meet the increasing social demands (of electricity, for example) towards sustainability.

To enable this aim, section 4.1 of this chapter explains the effect of multiple factors on the development of offshore wind system. This part answers the first research question: How do non- technical and technical factors affect the development of offshore wind system within the UK energy regime? The aim of this question is to understand how social actors characterise the offshore wind system (identifying its elements) and how they interpret the interaction of those multiple factors (elements) that affect the development. Section 4.2 aims to answer the second research question: How are the transition processes within the energy system affected by offshore wind development? What are the effects of the interaction between levels in the socio-technical transition processes on sustainability transition? The aim is to explore the effects of offshore wind development on socio-technical transition to understand the interaction between social actors and their context. And section 4.3 reveals the important role of social actors to shape a new technological system and to change its context by answering third research question: what is the role of social actors in the processes of socio-technical transition towards a sustainable low carbon electricity system?

4.1. Research Question 1: the effect of non- technical and technical factors

This section aims to answer the first research question: 'how do non-technical and technical factors affect the development of offshore wind system within the UK energy regime?' This part analyses the history and context of offshore wind energy in the UK. It is important to provide this background because the offshore wind system is characterised by its context since technology is embedded in its context. The research framework (Figure 4.1) illustrates the socio-technical nature of the offshore wind system whilst it recognises the co-dependent and context embeddedness nature of elements (technical and non-technical factors: technology and institutions) within the system during the processes of change.

Figure 4. 1 Socio-technical System



Therefore, the technical and institution elements of the offshore wind energy system that emerged from the interview data include: policy, market, the supply chain, technology and innovation, and natural resources. Arguably, these five areas have the most potential to be explored in terms of barriers and opportunities that affect the development of offshore wind. This provides an avenue to understand how social actors characterise offshore wind system and the impact of social aspects (context) on the development of this and to understand the systematic interaction between those multiple (technical and non-technical) factors that affect the development of offshore wind system. The importance of the study of natural resources is to understand the significance of offshore wind energy connected to its context: history, location, demand and growth.

4.1.1. Natural resources

Historically, (onshore) wind technology has delivered energy over centuries in the UK and Norfolk for varying purposes. Since the 1990s, onshore wind technology has become more industrialised for producing electricity and a lot of technology and innovation have been used to promote more efficient electricity production. Shifting from onshore to offshore wind is one of these technological innovations, which aims to generate electricity. The UK and especially the east coast of England has got good potential to develop more offshore wind projects to generate more electricity from wind. The first offshore wind project in the east coast of England, Scroby Sands, started in 2004 with thirty 2 MW turbines and an overall 60 MW capacity. To date, five offshore windfarms are in operation or under construction along the East Anglian coast (Table 4.1).

Table 4. 1 Offshore wind farms in East Anglian coast (Norfolk and Suffolk)

Offshore wind project	Capacity (MW)	Turbines	Turbine Capacity (MW)	Status Date	Status of Project
East Anglia One	714	102	7	17/06/2014	Approved
Galloper	336	56	6	24/05/2013	Approved
Sheringham Shoal	316.8	88	3.6	27/09/2012	Operational
Greater Gabbard	504	140	3.6	07/09/2013	Operational
Scroby Sands	60	30	2	01/12/2004	Operational

Source: Adopted from East of England Energy Zone and Renewable UK

4.1.1.1. Historical evolution of the offshore wind growth

History shows that the wind industry has been developing and shaped through human demand over decades.

> *"Wind industry is not new, we've been doing for centuries, hundreds of years in the UK but [for] very different reasons, onshore windmills to pump water and grinding wheat and flour. […] Onshore wind for power generation yes 20-25 years is one of the most mature technologies […] But offshore wind turbines might look the same, [but] it is completely different technology." (En.L2)*

> *"Onshore many decades ago we were looking at wind mills for moving water around fields and marshes and grinding wheat it was 4 blades, and that was for very different reasons. But offshore 3 blades and now currently looking at 2 blades design for a variety of reasons." (En.L2)*

Offshore wind technology has built upon the onshore wind industry which has been generating electricity since 1991 (Renewable UK). However, the technology that is used is dissimilar to that used for onshore wind.

4.1.1.2. The importance of location in developing offshore wind

The availability of natural resources is an essential factor for deployment of offshore wind energy. One of the significant factors that differentiates the East Anglian coast over other regions, in terms of the development of offshore wind projects, is the availability of potential wind (natural resource) and proximity to the shore.

> *"In terms of East Anglia we have a greater interest in offshore wind than in other areas. Probably only Hull and the Humber and Aberdeen have similar amounts of interest." (M.L2)*

> *"In any energy system, a country will look to explore natural resources that it has, it might be sun, hydro, wind. And the UK has a fantastic wind resource, so it would be silly not to take advantage of that." (P.N4)*

Therefore, location is one of the important factors that make the East Anglian coast attractive for the development of offshore wind.

"In the North Sea, in particular, there are a number of areas where the water is still quite shallow- 20 meters, 30 meters. Because the North Sea isn't an ocean […] so that is where the big developments can happen. And it also has predictable prevailing winds. Predictability is important, you want to be able to get your business model to get to say well if you put a turbine which is a 5 MW turbine or a 6 MW turbine in this area, then we can expect winds in this sort of area of magnitude in so many days in the year therefore we generate so much revenue. So that's predictable and accountable, and that's important."(En.L7)

"A lot of it is around location, so our proximity to the offshore market. The best location for a lot of the offshore wind farms are off the east coast of the UK, so with the natural resources there -shallow water, really good wind resource, technically and environmentally very feasible for these projects to be developed." (P.L5)

"Right now, the statistics suggest that, not only the UK have more installed capacity than the rest of the world combined but 69% of all of the UK capacity is off the coast of Norfolk, Suffolk, and Essex, 69% of that capacity is an enormous number." (En.L2)

The interview data shows that the East Anglia coast is playing a major role in the development of offshore wind in the UK both in terms of business growth and installed capacity, due to natural resources: availability and predictability of wind sources, and its location (in terms of both natural resources such as shallow water and proximity to the offshore wind market). This argument is evident by statistics and interviewee (En.L2) highlighted that the region is a world leader in terms of total installed capacity.

"Now that said, East Anglia has done very, very well in terms of its share of offshore wind development so something like 5 to 6 GW of offshore wind has been built in the UK to date or certainly will be built by the close of the Renewables Objective scheme in April 2017, of that probably about 2.5 GW has been built around the waters of East Anglia so that's a huge amount. Now we've got another 700 MW coming in under East Anglia ONE. There's also a project that is yet to complete but will be completed called Dudgeon, which I think is about 400 MW. So off the East Anglian coast we could have anywhere up to 3 and 3.5 GW of offshore wind which all has to be serviced, all has to be maintained and should create a sustainable industry for East Anglia even

without the additional projects, any additional projects coming through in later rounds."(M.L1)

Data shows that the East Anglia Zone has potential, with comparable conditions such as location, for developing offshore wind projects. Through the East Anglia Zone's potential the offshore wind industry can deliver large scale low carbon electricity to meet the UK emissions target for 2020. Furthermore, the location condition is a vital factor for attracting investment to the Zone and the UK, which emerged from the primary data.

"The UK is an attractive location for investment in offshore wind. The combination of natural resources (strong and consistent wind), favourable locations for turbines, a stable regulatory regime and a well-established and experienced industry has helped the UK secure its position as one of the global leaders in the development of offshore wind." (D8)

"In terms of inward investment, the major thing is location and obviously the opportunity of the North Sea which is a shallow sea and has lots of wind and is therefore an ideal location plus the UK government has supported in the early days the industry to make sure it grows and the UK becomes the centre of the world for offshore wind." (P.L6)

4.1.1.3. Demand and growth (evolution of the electricity market)

There is also a resilient belief that the UK has the potential to maintain its leadership position towards the low carbon targets that have been set.

"There is a limit to how much gas we can burn if we want to keep our emissions below, if we say we want to keep emissions below 100 grams of carbon dioxide, the most efficient gas generation produces 400 grams. So that means we can get one quarter of our energy from gas. We can't get any of it from coal. Coal is three times dirtier than gas. So what is left? We can have some nuclear stations but if you think we are going to have more than 4 nuclear power stations in 2030 just realistically we are not going to. We have got a bit of biomass, a bit of wave, a bit of tidal and a bit of hydro, that might add up to another 7.5%. When you add all of those up that gets you to 45% of the energy we are going to need. The other 55% has to come from solar, from onshore wind and from offshore

wind. Because of the weather we have in the UK solar should never be allowed to deliver more than 10% because of its load factor, so 45% of our electricity has to come from onshore and offshore wind." (P.N3)

"Offshore wind has much more rapid innovation in the technology and the commercial models and the technology innovation that goes with that. So, we are seeing in very, very quick succession new products, bigger turbines. The industry standard a couple of years ago, was a 3.6 – 4 MW turbine. The standard now for planning purposes is a 5 MW, 6 MW, 7 MW turbine, and who knows in the next few years we will start seeing 10 MW turbines coming out of development. And that is the direction of travel for this industry, bigger turbines, bigger blades, swept area of blades more efficient, power station offshore rather than large numbers of turbines we will see a smaller number but greater capacity. And that is going to be always thinking of natural evolution of the industry." (En.L2)

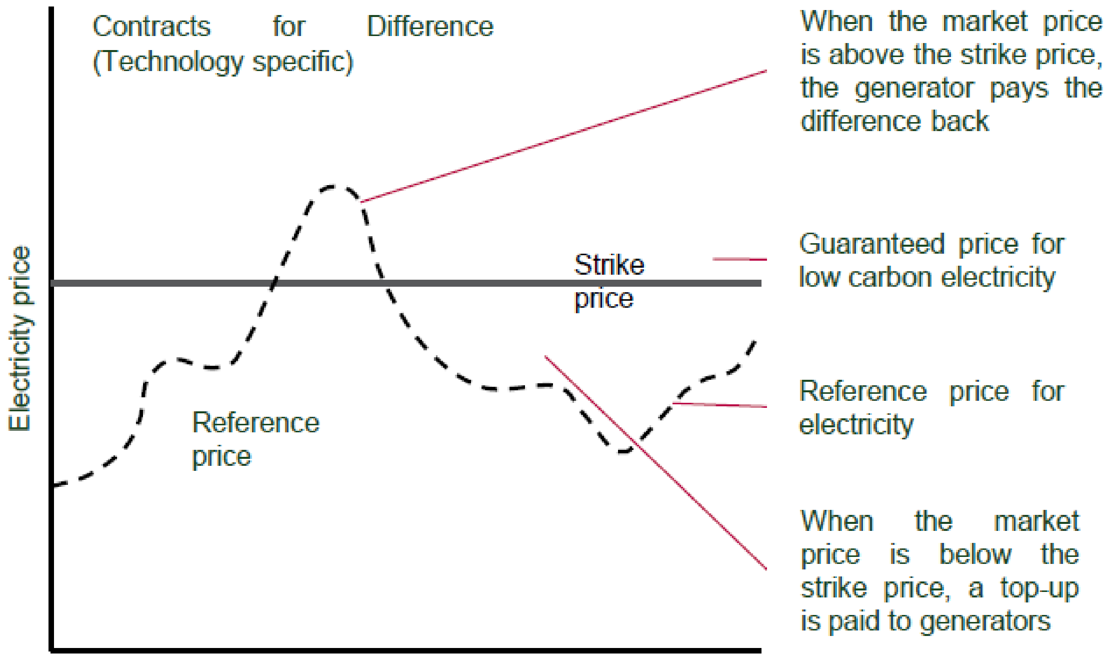
Since 2004, when the first offshore windfarm was operated on the East Anglian coast, the UK offshore wind energy sector has become more industrialised. However, there are still a number of barriers against the development of offshore wind, as well as opportunities for future development, which were observed during the fieldwork and emerged from the data analysis. Based on primary data, there are four areas that participants identify as key in terms of barriers against the development of offshore wind and to promote opportunities. Policy is one of the key areas that was noted by all participants which will be analysed in the next section. The other areas are included: the supply chain, the market, and technology and innovation, which will be discussed in the following sections respectively.

4.1.2 Energy policy and introduction to Contract for Difference

The importance of a long term view of policy is a key theme which was highlighted by a majority of participants. The energy policy development in the UK introduced new schemes in addition to the Renewable Obligation (RO) which will come to its end by 2017. The new scheme, the Contract for Difference (CfD), introduced in 2014, is an awards subsidy contract for renewable energy developers to compete in annual auctions held by the Department of Energy and Climate Change (DECC) to win subsidy contracts at the best possible price for end users. The CfD forms part of the UK

Electricity Market Reform programme. It is expected to continue until the end of the decade (D16).

Figure 4. 2 The CfD mechanism



Source: UKIT (2015)

According to the CfD scheme (and illustrated in figure 4.2), a *"guaranteed price" (D8)* for electricity from low carbon technology specific sources is contracted between the government (DECC) and a low carbon electricity generator. The generator is paid the difference between the cost of investing, *"strike price" (D8)* and the average market price for electricity, *"reference price" (D8)*. DECC emphasised the government aims and ambition through the designing of CfDs as: *"CfDs are designed to give investors the confidence and certainty they need to invest in low carbon electricity generation, helping the UK electricity sector to attract greater investment in low-carbon generation, and subsequently reducing the UK's carbon emissions." (D10).* It is also documented by DECC that *"This reduction in risk and increased level of certainty reduces the borrowing costs that investors face – and this saving is passed through to consumers in the form of lower expected support costs to renewable generators." (D11)*

Table 4. 2 Offshore wind farms awarded CfD

Offshore wind project	Location	Capacity (MW)	Turbines	Turbine Capacity (MW)	Strike price (£/MWh)
East Anglia One	43km off Norfolk and Suffolk coast	714	102	7	119.89
Near na Gaoithe	15km off the Fife coast, Scotland	448	64	7	114.39

Source: Data adopted from DECC and Renewable UK

The CfD was instituted in line with the UK Energy Act, being auctioned for the first time in February 2015, awarded to two offshore wind projects East Anglia Phase One (East Anglian coast), and Neart na Gaoithe (Scottish coast). These two projects contribute to a total of 1162 MW capacity (D15). Statistics show that the UK offshore wind pipeline built approximately 4.3 GW installed capacity and 1.7 GW is under construction. Among them 1.4 GW is under RO support, and 3.7 GW is subsidised by CfD, while a delivery target has been set at 10 GW for 2020 (D8 and Renewable UK).

4.1.2.1. Subsidy through the Contract for Difference

The offshore wind industry is dependent on financial support from both the public and private sectors. The rationale is that the offshore wind in terms of industry status is still immature. The other reason, which links with the industry status, is that the processes of building an offshore wind farm from planning permission phase to developing the project take a long time. So the secure subsidy and long term policy enables developers to invest in the long development processes in terms of time scale.

> *"Long term certainty, is something that private sector, developers, operators, the whole supply chain was calling for, but government has not been able to provide long term certainty as yet."* (C.L7)

> *"Offshore wind is dependent on financial support and therefore the whole industry is looking for predictability from the government not for 1 and 2 years but for 4, 5, 6, 7, 8 years perspective. Because it takes around 1 to 2 years to develop a product and get the manufacturing line and then they need 5 years payback time on what they have invested in to do it and then you are up to 6,7,8*

years. So we all need to bring this industry forward and predictability for that period of time." (SC10)

"The main barrier is ensuring that enough money is being released frequently enough to send the right signal to developers to continue with their projects. So at the moment the government is running annual auctions to award contracts to offshore wind projects so it is only releasing small amounts of money each year. So as an example, in the recent auction […] they only spent about 260 million pounds which is enough to bring forward about 1.2 GW of offshore wind projects. If you look at the total pipeline of offshore wind in the UK it is probably about 15 GW and if you look at what could come forward between now and 2020 it's probably about 6 to 8 GW."(M.L1)

In relation to the UK government's new energy policy *'Contracts for Difference (CfD)'* participants highlighted the importance of a long term view of energy policy through the CfD, which affect the industry's confidence to invest in offshore wind projects. The interview data shows that the subsidy that has been introduced for offshore wind and is being auctioned through the CfD is unable to provide certainty for the industry because the long term availability of the fund is uncertain. A range of opinions from the interviews stressed how certainty in energy policy has a direct effect on investment in offshore wind projects, subsidies and industry confidence.

4.1.2.2. The effect of Contract for Difference on offshore wind investment

Based on analyses of DECC's reports, the government aims and ambitions of CfDs are to increase investor certainty and stability. However, most participants believed that the new energy policy, CfD, set by government will not bring long term certainty for the offshore wind sector.

"The policy future is still very uncertain. The introduction of CfDs has not brought in more certainty in some ways. It has brought in more uncertainty, because you have created yet another barrier for developers to push through." (C.L4)

> *"An industry like offshore wind needs long term visibility like what government plans in terms of how they would like to resource energy, let's say, in 10-15 years because without having certainty or at least clarity about what is the intention of the government, it is difficult to plan for the investments in this very long time frame."* (P.N2)

> *"In the UK typically what's incentivised [for] private companies to build offshore wind projects is long term financial support through government support schemes. So historically that's been done through something called the Renewables Obligation which comes to an end in 2017. And it is being replaced by something called Contract for Difference which has been auctioned this week [the auction took place on 26/02/2015] for the first time. Both those schemes provide very long term financial support so the Renewables Obligation provided 20 years of payments for generation by offshore wind projects and the Contract for Difference provides 15 years of support. So government is providing the financial incentive but it is still for private companies to come forward and take the risk to build the projects, and operate the projects. So long as they do that and they generate electricity, for every unit of electricity they generate they will receive a support payment from government."* (M.L1)

The interview data demonstrates that the uncertainty towards the future of subsidy, post 2020, has an effect on the investment into further offshore wind projects. While from the government point of view *"the CfD reduces the risks faced by low-carbon generators, by paying a variable top-up between the market price and a fixed price level, known as the 'strike price'. As well as reducing the exposure to volatile and rising fossil fuel prices, the CfD protects consumers by ensuring that generators pay back when the price of electricity goes above the strike price."*(D11)

> *"At the moment we have some certainty out to 2020 through the 'Contracts for Difference' mechanisms, however there are some particular issues within that, however there is no guarantee, there is no certainty beyond 2020. So projects and investors in projects are not able to take a long term view in new offshore wind projects."* (C.L1)

Further to that, it was commented that the availability of subsidies is uncertain for the remaining four auctions until 2020.

> *"The problem is that they've got it now and now there are going to be 4 more auctions to 2020. Those auctions are going to have a smaller and smaller pot each time of budget. And offshore wind projects aren't your standard 10 MW, 15 MW, they are not small. No one build 3 turbines offshore, no one does 5. It is a 100 turbines it's 50 turbines whatever. So they are going to try and bid in with a big project for a smaller and smaller amount of money each time. And so we've worked out that each year the CfD can support around 800 MW of offshore wind which is around one big farm, for example the East Anglia ONE is around 800 MW. So it's one a year basically."(M.L2)*

In summary, based on data, although the CfD brings some levels of certainty, however, from the industry (developers) point of view, there are some degrees of risk. Interview data showed that, the way in which CfD is being implemented, increases the overall risk in terms of investment. Although it increases competition in terms of price (Table 4.2), it is unlikely that developers are willing to invest in new projects while the overall risk and uncertainty is relatively high.

4.1.2.3. The effect of Contract for Difference on industry confidence

It was evident that the introduction of CfD brings additional uncertainty to the long term policy view for the offshore wind development in terms of investment. The rationale behind the effect on investment is the industry confidence which emerged from the interview data. The uncertainty about the policy future prevents the industry investing in further development.

> *"The recent constraints on the Contracts for Difference budgets have meant that the offshore companies cannot look to fund the large parcels of that development they were looking forward to. In fact they may have to reduce their yearly package size by about half which if they do is going to put up the costs of production. So we are not quite sure how we are going to benefit from this […]." (P.L3)*

> *"Companies at the moment are just looking at a couple of years into the future to see what is going to happen so they don't have any long term visibility." (E.N2)*

"Every time they run an auction process and developers miss out on securing a contract it makes them question whether it is worthwhile waiting for the next auction. So I think we could see some attrition each year as contracts are awarded, but a number of developers miss out on receiving those contracts. As a further example, even though in this auction that's recently concluded, I would say 1.2 GW of contracts have been awarded to offshore wind projects, but there is probably about 3 to 4 GW of projects that didn't win the contracts and those projects now will be reviewing their options as to whether they continue developing them or whether they decide to abandon them. So in terms of barriers that's the major barrier. […] in that sense, that's obviously going to be disappointing for the offshore wind industry." (M.L1)

The data shows that the industry requires some certainty of future energy policy, since the offshore wind project planning consent requires the industry spend considerable time and investment. Yet, the new energy policy, CfD, has added uncertainty for the future investment for the offshore wind projects due to being announced annually. The annual subsidy under the CfD scheme also affects the industry confidence due to the limited subsidy available each year, and with considering the offshore wind large scales projects and planning consents, there would be additional uncertainty to win the CfD auction.

"They need to build the wind farm, and if they don't get the subsidy at the end of this month then it puts the whole thing at risk because they will be sitting there trying to decide 'do we proceed with this project or do we just get out because we've spent millions already and we're not getting anywhere." (E.N2)

"I think we will see a second round of CfDs and then those people that have lost twice will start to consider whether they should pull out altogether and focus their attention on other more lucrative ways of making money. Because despite what the public seems to think, a company doing this development is there to make profit for its owners and its shareholders, it is not there as a charity, so it is not going to sit there waiting year after year after year to apply for yet another auction that it may still be unsuccessful in." (C.L4)

"What the industry really needs is much greater clarity on what the budget is going to be made available for CfD is likely to be post 2020. Because at the moment all we have is a spending envelope up to 2020 with the government releasing small chunks each year to award new CfDs. But a lot of the projects now that are looking to make investment decisions are going to be commissioning after 2020 and they need to know how much money is going to be made available to them to support their projects, and they don't know that." (M.L1)

From the analysis of interview data, it has been discussed by a number of participants that future uncertainty in government policy impacts industry confidence to invest in offshore wind projects, so these two sub-themes (industry confidence and investment) are tied.

In summary, in the process of developing a new technological system within the established socio-technical regime, it is necessary to identify and to characterise the effective factors that influence the development. Policy is one of the main factors that was highlighted by scholars in socio-technical transition studies. Policy was also identified by all participants in this study as a key factor that influences the development of offshore wind. The data shows that a long term view of the government policy heightens the degree of investment in offshore wind projects. Because the development of an offshore wind project requires long term contracts and commitment from the early stage of planning permission to operation, the industry needs to have long term visibility of the policy. This is vital for the development of offshore wind as then more investment will come forward.

4.1.3 The offshore wind supply chain

According to the Renewable UK definition *"Supply chains are the movement of materials as they flow from their source to the end customer. In the wind and marine renewable sectors these include the manufacture, transport and installation of wind turbines, wave and tidal devices, and supporting infrastructure such as foundations and cables."* Based on this view, the offshore supply chain is playing a central role in the development of offshore wind and in securing the cost of technology.

The UK government in August 2013, in collaboration with industry, developed the offshore wind industrial strategy:

> *"Industry and Government work together to build a competitive and innovative UK supply chain that delivers and sustains jobs, exports and economic benefits for the UK, supporting offshore wind as a core and cost-effective part of the UK's long-term electricity mix." (D9)*

The offshore wind supply chain in the UK is a young industry, yet, it potentially makes up a constituent part of the UK energy mix.

> *"Offshore wind is a proven technology which has developed in the UK through 16 years of government support." (D8)*

The offshore wind supply chain has a major role that *"… delivers and sustains jobs, exports and economic benefits for the UK."(D8)* Data shows that the current offshore wind market size is at *"5.7GW installed and under construction, and is on track to deliver 10GW by 2020" (D8).* This denotes a large development in market size, which indicates the role of the supply chain. However, the challenges are how to build a cost efficient and innovative offshore wind supply chain that is capable to deliver these goals. The next sections analyses the capability of the current supply chain.

4.1.3.1. Transferring technology

The offshore wind supply chain has evolved through transferring technologies and experience from other offshore energy sectors like oil and gas. Because all of the activities such as the oil and gas exploration, production, storage, decommissioning of the offshore assets, have a major common engineering and business core and the supply chain that are delivering those projects have a diverse portfolio.

> *"... when people talk about the offshore wind supply chain, you can't say here is a list of companies […] because there are very, very few and far between the companies that 100% focus on offshore wind. Some of the more successful companies are 50-50 with another industry whether it's marine, or maritime, or defence, or oil and gas, or aerospace, and offshore wind is a part of that business." (En.L2)*

The offshore gas industry on the East Anglian coast has approximately 50 years of experience. Within this theme a wide range of local participants asserted that transferring skills and experience from other offshore sectors which they are good at, like oil and gas, has had an effective impact on the offshore wind industry and provides a reliable account for the local supply chain becoming part of the UK supply chain for offshore wind.

> *"The oil and gas industries have matured over several years and have developed strategies. The wind industry is still developing the strategy for doing it. Well there is a lot of best practices in place already and we take the view that why you don't make use of what has already been done for other sectors. The challenges are much the same. You are building expensive items at sea in harsh weather environments." (SC1)*

> *"I think certainly it is going to be very tough to develop offshore wind in a large scale offshore environment without taking lessons from oil and gas. [Our company]'s background started off in offshore oil and gas and has actually moved into offshore wind but we still work in both. But actually about 70% of our turnover comes from offshore wind nowadays and I think what we have done and other people have probably lacked, we have taken some of the mind-set of oil and gas, some of the common sense, and some of the health and safety mind-set, and taken that into offshore wind." (M.L3)*

> *"Our business is based mainly in the oil and gas market and we are transferring that knowledge. I think that the things that Renewables UK needs to do is that. Companies like ourselves base our knowledge and expertise in working in offshore wind from our 40 years of experience working in the oil and gas sector." (SC1)*

4.1.3.2. Transferable skills

Within the offshore sectors, there are a range of common skills that can be transferred. The offshore wind industry in the East Anglia region benefits from the offshore skills which have developed through the established offshore oil and gas industry. It is important to identify crossover between skills in offshore industries and to use/ re-use skills. Because the offshore wind technology is expensive so it would be an option for offshore wind developers to reduce the cost of technology by transferring skills from the oil and gas industries.

> *"I think from my experience of working in oil and gas as well and doing research on it, transferable skills are probably one of the ways that the region could cheat, as it were, and other regions can't cheat. Only Aberdeen probably has got the potential to transfer all that knowledge and offshore skill and flip it into offshore wind. However, they are so focused on oil that this region has got the opportunity to do that. So the transferable skills are there, there are quite a few companies who do both, who do offshore operations and maintenance for oil and gas and for offshore wind." (M.L2)*

> *"Both towns that is Great Yarmouth and Lowestoft have worked in the offshore oil and gas industry for almost 50 years now. So we are very experienced at working both offshore and making onshore provisions. We have a highly qualified workforce with transferable skills." (P.L3)*

> *"We are good at engineering and solutions to issue things. So our companies can help with their engineering, maintenance, sort of operations and maintenance of the wind turbines, you need engineers to understand hydraulics and gearboxes and all those things and electrical installations. […] So those people exist, they do now in oil and gas business, so there is a cross over there. […] Transferring skills from oil and gas have benefits for developing offshore wind in the region] because we don't need to start from scratch, we understand safety, we understand marine conditions, and we understand just in time […]" (P.L2)*

The interview data shows that the local supply chain has advantages of long term experience in offshore oil and gas. As participants commented, there are technology and skills in common that are transferable to the offshore wind sector. Also transferable skills have an effect on the offshore wind development since this advantage prevents the supply chain from starting from '*scratch'*.

4.1.3.3. The importance of specific skills

The offshore wind technology is relatively new so requires specific skills in different parts of the processes. These specific skills; however, are not transferable from other offshore industries.

> *"Approximately 80% of the skills are common to all of the primary energy production sectors, that 20% is going to be specific. Now that gives us both the strategy to allows people to move into sectors where there are jobs when they are needed but there are also plenty of other bodies that look after offshore wind, or nuclear or oil and gas, and particularly at the lower levels where the priority should be 'people skills' rather than what sector they work in." (En.L5)*

A dominant issue for some participants was that despite the offshore wind supply chain taking advantage of being able to transfer skills and experience from established industries like oil and gas, there are still specific skills that are required by the offshore wind industry initially. Within this theme, however, skills has been highlighted by a number of interviewees through discussion.

> *"A wind farm is not like the oil and gas platform, a wind farm has 100 things spread over many square kilometres, it doesn't have one static thing in the middle. So there the element in offshore wind industry is not like oil and gas and not like marine engineering and not like the electricity industry either. Probably most of the people who work in offshore wind they actually come from [the] onshore electricity industry and that means we're missing a whole raft of the skills. The one we miss the most are the people with that decade of experience to really work in offshore, certainly when you're design and permitting at the project management stage of the project and that lack of real offshore experience has led to the early project's being delivered more slowly and more*

expensively than they should. Because people with an onshore mind set had to learn about offshore." (SC5)

The lack of skilful workforce affected the early offshore wind projects, since the only availability of skills was from onshore wind and oil and gas industries. The absence of specific skills caused delays in the processes of operations of early offshore windfarms.

"The lessons learned from the oil and gas sector are not being passed on to the wind sector and they have got to realise that they need to do it the oil and gas way. That is just not true. If we are simply going to do it in the way that we did it before then we are going to get what we got before. And what we got was great for a highly profitable product such as oil and gas but it is not going to be useful in a very highly competitive electricity market. […]That sort of taking it the way that we do it with oil and gas is not good enough. We have to think differently. So we have to go beyond the experiences of oil and gas and actually take new ways of thinking, new ways of developing, new ways of servicing and new ways of operating that were never felt to be a good thing for the oil and gas sector. So for me you have to throw the oil and gas rule book out of the window." (C.L4)

Furthermore, the experience from the oil and gas industry although helpful for the offshore wind, it '*is not good enough'* if the development is to be focused. The transferred methods need to be methodologically changed then translated to offshore wind. For offshore wind to grow, it requires specific skills along with the skills in common with other offshore energy industries.

"We now need physical engineers, construction engineers right across the board from the most simplistic job of laying a brick or pouring some concrete somewhere right through to the high tech jobs of undersea surveys, technical engineering, computer sciences, nuclear sciences, all those aspects. And it is really trying to catch up from that period of people not coming forward from apprenticeships and that is quite a challenge for everybody." (P.L3)

"We have a high level of transferable skills but a very high proportion of those skilled people are in their mid-50s and when they get to retiring which is about that age for offshore there is not the workforce to come forward that doesn't just apply to offshore, it applies to carpenters, bricklayers, concreters, steel fixers, all the people who have been involved in the construction industry." (P.L3)

Those common transferable skills in the region at retirement '*age*', while offshore wind projects require long term skills, since the longevity of a windfarms is estimated at 20-25 years.

> *"We are currently running apprenticeship schemes which help people get into the offshore gas and renewables industries. That is something that has been very important to us. We need to be able to call on that workforce and for it to actually grow and we want people to be able to get into the industry and make a job for life really. Because, as you know, there is going to be the development of the East Anglia sites over the next ten, twelve years probably, if I am honest and if you consider all those wind farms are going to be generating for another twenty years at least so you have got forty years potentially of work or, well people working on one particular asset over the course of their career. That is as solid as a career as you can ask for really." (SC14)*

A range of opinions emphasised the importance of developing partnerships between the industry and educational organisations such as universities and colleges in terms of training specific skills that the offshore wind industry requires. In fact, the industry in collaboration with educational organisations can fill this gap. Within the theme apprenticeship, graduate schemes and particular courses have been highlighted.

4.1.3.4. Standardisation in the local supply chain

Since the offshore wind industry is young, standardisation in the local supply chain is a fundamental approach for development. Standardisation provides effective abilities for the supply chain to improve the entire sector. A standardised supply chain enables the industry to develop and to mature the technology in use. This reduces the cost of technology and leads the offshore wind to be part of the energy mix.

> *"The local supply chain here is largely a service based industry. Norfolk and Suffolk have largely been a service industry for oil and gas, mostly gas of our region. But have been servicing oil platforms of north and central North Sea as well as internationally. So it has grown up and developed as a service industry so expression and service place. All of that learning is being transferred into other sectors such as offshore wind. So looking at cost, a bigger amount of cost is maintenance, looking at improving maintenance techniques." (C.L1)*

As participant (C.L1) commented the local supply chain is service based and also there is not a pure supply chain for the offshore wind in a wider context even (all offshore activities as a diverse portfolio are common between multiple sectors, like oil and gas). So, for the local supply chain which is well experienced in multiple aspects of the offshore energy activities, it is important to standardise.

4.1.3.5. Standardisation and networking

The local supply chain needs to be standardised and to be able to deliver standardisation in different elements of operation and maintenance. Transferring skills and experience is a sufficient approach at some points, because the local supply chain does not need to start from an early level- as participant (P.L2) mentioned from *'scratch'*. However, the supply chain needs to grow and to compete in the global market through standardisation. One approach is to increase collaboration between the energy industry and the local supply chain.

> *"The region's energy sector must push its decades of skills and experience towards the global market [...]" (F.E1).*

> *"There's a hub of 50 years' worth of experience and that hub can work globally. We need to think how do we use that experience to make the pie bigger." (F.E2)*

> *"This region or this area has got lots and lots of good small companies that do a lot of work in supply chain but it hasn't got the big guys at the top who can filter down contracts in to the market and get the revenue journey. I think the attractiveness is the key thing to attract the bigger players to set up to then be able to build a supply chain. I think the structures are in place, it is just getting those bigger guys in, that would be my main point." (M.L2)*

> *"A company like ours has a very strong track record of installing submarine cables and on much larger projects than most of the offshore wind farms require and yet those developers still struggle to recognise us as a qualified and competent supplier." (C.L4)*

A range of opinions indicated the importance of establishing a strong network between the local supply chain and the energy industry to further collaboration. There are a good number of best practices to drive supply chain standardisation that can develop through the networking and collaboration.

As highlighted by a range of opinions through the interviews, the key issue of standardisation of the local supply chain is to grow networks within the sector. Networking provides the local supply chain opportunities to collaborate with the energy industry for further transferring skills and technology through joint projects and through sharing best practices. Then this leads the local supply chain to develop faster and efficiently use and manage resources. Participant (EG) commented: *"they [operators] haven't changed what they are doing, they have just tinkered with bits and tried to iron out some of the inefficiencies in the system."* While participant (SC2) stressed the fact that continuity is a key for [the] local supply chain to grow: *"the more you do the better you get"*, and participant (P.L2) further noted that *"they [offshore wind developers] need to do this and they allow they come in the first phase they learn lots of lessons and in the second phase they are better at it and then the third phase you wouldn't believe that they could do it."* A standardised supply chain is able to do more projects, it *"allows everybody to get better, it allows you to invest in the market, invest in better equipment, invest in better ideas, do the research and development." (SC2)*

A more standardised supply chain can accelerate the whole sector effectively and deliver the technology through efficient use of resources. This allows the sector to develop and to mature the technology. Increasing the level of standardisation provides the supply chain opportunities to do more projects on a regular basis which leads the supply chain to grow. So within this theme (standardisation) networking and collaboration emerged which link to continuity, joint projects and sharing best practices. The latter three are felt to be essential for the local supply chain to grow.

4.1.3.6. Industrialisation of the offshore wind supply chain

This part takes the picture slightly wider and includes the wider offshore wind supply chain rather than focusing only on the local one. Since the offshore wind industry is still developing, the key issue is to reduce the cost of technology. This aim is achievable through increasing the capability of the supply chain. The previous section illustrated a more standardised supply chain capable to deliver technology efficiently and to speed up the sector. This part shows the industrialisation in different aspects of the supply chain in line with standardisation is momentous.

> *"I think that a more steadily growing industry actually makes it more easy for cost reduction methods to be implemented and it means that the main market players in the industry are actually getting a chance to incorporate lessons learnt rather than building a large and fundamentally unbalanced industry." (SC14)*

> *"We are moving from kind of the cottage industry through the various phases of industrial revolution. And now we are looking at serial manufacturing, serial industrialisation of offshore wind energy as a technology and as an industry. And that's going to natural maturity of this as a new industry." (En.L2)*

> *"Going forward, we need more industrialisation in the industry and that requires the volume of that to get there, to let the supply chain dare to invest." (SC10)*

Therefore, an industrialised supply chain provides opportunities to increase generation of electricity and to reduce the cost of operation.

> *"The future of offshore wind, it means the trends the offshore wind is growing and growing rapidly. Now it is still a very immature industry and still requires a level of support from the public sector to deal with risks and investments, to create a stable policy framework which will enable investors to deliver projects. It needs the government supports, not necessary subsidy, because the industry now recognises it needs to reduce its cost base, become competitive on a cost per MW h or cost per KW h depending on the technology but it needs to be cost competitive with other industries." (En.L2)*

The above quote noted that the offshore wind industry is required to reduce the cost of energy to be competitive which indicated the importance of industrialisation. Participant (EG) emphasised a degree of inefficiency within the supply chain: *"there is lots of inefficiencies in the way that offshore wind is managed at the moment"*. So the supply chain is capable to increase efficiency through standardisation and industrialisation which links to the cost of energy. Therefore, the supply chain plays a major role which highlights the importance of the industrialisation of the supply chain in relation to reducing costs.

> *"It [offshore wind] is still young but we have proved that the cost is going down and it is going down faster than the government anticipated. And that is a good signal. With all new technologies you need some time and volume to mature the industry so it will bring the costs to the level with other mature energy sources. Because that is also valid for oil and gas and everything else." (SC10)*

> *"The key to reducing costs is industrialisation and industrialisation would be made possible by having a very clear policy statement and a long term target which allows people to be able to plan towards that and support it with the investment required to achieve that. In a way we are caught up between a drive to push the prices down and long term certainty." (SC4)*

The key issue in the offshore wind industry is to reduce the costs, although within this theme participants suggested different aspects. Collectively they believe that cost reduction is achievable once the supply chain becomes more industrialised by emphasising the continuity of projects, more standardised and efficiently managed resources, skills and experience, and technology related to projects which reduces the overall risk profile of offshore wind projects such as the installation costs and timings, turbine availability, and operating and maintenance costs. When the offshore wind supply chain becomes more industrialised, the opportunities to generate more electricity will increase and the market share for offshore wind electricity will be increased.

4.1.4 The offshore wind market

The offshore wind market is a global market, even though the majority of development and potential is concentrated in the North Sea and northern Europe. *"The eastern coast of the UK has so much potential to be positioned as a leading centre for developing offshore wind farms across the SNS [Southern North Sea]…" (F.E5)*. It was also evident from the interview data that the East Anglian coast, in terms of *"proximity to the offshore market" (P.L5)* has potential to grow. As mentioned above and pointed out by participants (C.L1) and (P.L3), the local supply chains are also capable to transfer their experience, technology and skills from the oil and gas industries which they are good at. By taking these two advantages, the UK has the potential market positioning to compete globally in the offshore wind market.

"The European industry and market potential is probably the largest in the world [...]. And then from the UK point of view, the UK share of the European market place is, by far, the biggest. And if you take the UK out of the European context then it is the biggest global opportunity. Because of predictability of wind, the land conditions that evolved and the distance from windfarms to port as well. All of that make it a very attractive market for businesses to break into." (En.L7)

There is a growing recognition that there needs to be a large share of offshore wind in the UK energy mix due to growing electricity demand and meeting the emission targets.

"I would put it [the offshore wind] as part of the energy mix, in that it is a useful contributor to what we need. It is still relatively early days but we are also very, very dependent on things like coal and the gas industry. As you know there are times in the middle of winter when we really need electricity generation, we can't get it from wind it has to come from somewhere else. So it has a role to play. I will give you an example, at the moment and this is live at the moment, coal is at 33%, Gas 25%, wind is only 10% of the electricity generation in the UK." (En.L5)

"My calculation, looking at the energy this country is going to need in 2030, I think we will have between 25 and 30 GW of offshore wind by 2030. And that will be providing perhaps 30% of all our electricity and I can't see any other way that the UK is actually going to get its electricity in 2030." (SC5)

It was evident from the data that offshore wind is playing a crucial role in the UK energy mix. Statistics released by DECC suggest that 24.7% (equivalent 83.3 TW h) of total electricity was generated from renewable sources in 2015 (Figure 4.2) and the share of offshore wind was 17.4 TW h, represented 21% of renewables generation. The report also shows that the electricity generated by offshore wind rose 29.9% compared with 2014 (D12). These statistics are illustrated in Table 4.3.

Table 4. 3 UK Electricity Generation 2015

	TW h	% of total generation	Compared % with 2014
Renewables	83.3	24.7	+28.9
Offshore wind	17.4	5.2	+29.9
Onshore wind	23		+23.7
Hydro energy	6.3		+7.4
Solar PV	7.6		+86.6
Bio energy	29.0		+27.8
Coal	76.3	22.6	-24.3
Gas	99.8	29.5	-1.2
Nuclear	70.3	20.8	+10.3
Oil and others	8	2.4	No data
Total	337.7		-0.4

Source: Data adopted from DECC (last update 31 March 2016)

Statistics show an increased capacity in 2015, the share of renewable electricity generation increased to 24.7%, from 19.1% in 2014 (D14).

Table 4. 4 Renewable Electricity Share, Comparison 2014-2015

	2014	2015
Renewable Generation (TW h)	64.7	83.3
Total Electricity Generation (TW h)	338.9	337.7

Source: Statistics adopted from DECC (last update March 2016)

While the statistics indicate the effect of natural recourses and location in increasing electricity production from offshore wind, it also highlights the potential for market growth.

"These increases were due to increased capacity and high wind speeds, with average wind speeds in 2015 the highest in the last fifteen years, and 0.6 knots (7.2%) higher than a year earlier." (D12)

Due to the embeddedness of the offshore wind technology with location and considerable availability off the southern North Sea and specifically the eastern coast of the UK, the offshore wind market has significant potential to grow. Therefore, the offshore wind relatively meets the electricity demand within the diverse energy mix. Another qualification factor for offshore wind to be part of the energy mix is the capability of offshore wind to meet energy security requirements.

"I think in the UK you are going to see a reduction in terms of gas generation over the next few years […] and also you are going to see a lot of the assets in the southern North Sea which are going to come into decommission because of the lower gas price which is going to mean that the overall energy price across the UK is probably going to increase quite significantly which means it is going to play into the hands of offshore wind." (SC14)

"The other global factors, the oil price, […] we've understood that there has been an overall decline in oil production and gas production around the world, which means it is a finite resource, then we have to manage carefully, therefore, fluctuation in price. We have shale oil and shale gas in the US, which is not distorting the market, it is changing the market in a way that people haven't thought of before. So prices bottom out so we looking at below 50 USD a barrel for price of oil. So that's putting on all sort of pressures on industry, supply chain, great of consumers, petrol plant, it is not helping jobs in commerce." (En.L2)

The interview data demonstrates the effect of global energy price on the energy mix. This adds another important comparable advantage to highlight the role of offshore wind in the energy mix to address energy security. Furthermore, offshore wind is potentially a key contributor to meet emissions targets. So within this theme 'energy security' emerged.

"We delivered our commitment [under the Kyoto protocol] because we shifted from coal and oil fire power generation to gas-fired power generation as well as

developing our renewables capacity. Because gas as a hydrocarbon has a much lower carbon content than oil or coal." (En.L2)

"There is a limit to how much gas we can burn if we want to keep our emissions below, if we say we want to keep emissions below 100 grams of carbon dioxide, the most efficient gas generation produces 400 grams. So that means we can get one quarter of our energy from gas. We can't get any of it from coal. Coal is three times dirtier than gas. So what is left? We can have some nuclear stations but if you think we are going to have more than 4 nuclear power stations in 2030 just realistically we are not going to. We have got a bit of biomass, a bit of wave, a bit of tidal and a bit of hydro, that might add up to another 7.5%. When you add all of those up that gets you to 45% of the energy we are going to need. The other 55% has to come from solar, from onshore wind and from offshore wind. Because of the weather we have in the UK solar should never be allowed to deliver more than 10% because that is its load factor so 45% of our electricity has to come from onshore and offshore wind." (P.L3)

"The operations of these wind turbines is 25 to 40 years, so the jobs created are commitment in time so it's not come and build in and going away, it is come and build in and look after it […] They reckon about a job per wind turbine, so there might be a 1000 of jobs or 1200 jobs involve in this [East Anglia Array]. But those jobs should be there for the future. […] So there is opportunity for generation of work, 30 years, 25 years of work." (P.L2)

The UK is shifting to use more low carbon sources of energy in the energy mix to deliver the EU commitments as well as the UK Climate ACT (which requires 80% emissions reduction from 1990 level by 2050) in the absence of a global agreement such as Kyoto which expired in 2012. The above quotes demonstrate that in order to respond electricity demand and to deliver emissions targets, there needs to be a shift from coal and gas to new alternative sources of energy. This leads to a shift from a high carbon economy to a low carbon economy and jobs created in this sector. So, the theme 'low carbon economy' emerged in relation to jobs creation. Overall, offshore wind is a contributor to meet electricity demand and emissions targets and is also a major driver in the green growth economy by jobs creation. These factors highlight the crucial role of offshore wind in the UK energy mix.

4.1.4.1. Long term market visibility and cost reduction

The interview data shows that the offshore wind industry needs to have long term visibility of the offshore wind market, to give them confidence to enter and to invest and also to compete within the established electricity market. On the other hand, the government will promote the offshore wind market once the offshore wind industry reduces the cost of energy. So within this theme ‘cost’ emerged.

> *“Full realisation of the cost reductions will be achieved through industry building on real experience which again depends on a sustained, growing market.” (D1)*

The offshore wind industry is required to reduce the cost of electricity production, the achievement of this goal depends on market growth. So a sizable market and cost are two themes that connect with each other.

Participant (C.L4) noted: *“I think the cost of offshore wind, it could be argued for a long time but it will still be high unless we change the model [Levelise Cost of Energy].”* This again highlights the effect of policy.

> *“If we look at what the government is trying to do, with things like the CfD and the auctions process, and even the CfD auction recently government came under a lot of pressure. Because the amount of money and amount of support that has been made available. I think what the government was trying to do was perhaps get in the wrong way round but forcing the industry to reduce its cost much quicker than perhaps the industry was ready for and there needs [to be] the compromise in the middle. Industry has to reduce its cost and industry knows.” (C.L2)*

> *“Costs in offshore wind development appears to be going down very, very quickly so a report was released yesterday (interviewee mentioned 26/02/15) by a firm called ORE Catapult. They conducted a major study into offshore wind cost, development cost, in the last four years and I think it has shown that it has come down by 14%. And the government set a target for offshore wind costs to be around £100 per MW h by 2020. What the report, which was released yesterday, signifies is that we are on track to reach that.” (M.L1)*

A range of the industry views, as quoted above, stressed that the CfD adds pressure on the industry in the way the future of the offshore wind industry depends on how to deliver cost competitiveness with other industries. This is evident with the quote from the Energy Minister Amber Rudd's speech on a new direction for UK energy policy: *"if, and only if, the government's conditions on cost reduction are met, we will make funding available for three auctions in this parliament"*. She also added: *"the industry tells us they can meet that challenge, and we will hold them to it. If they don't there will be no subsidy. No more blank cheques." (18 November 2015).*

This view is supported by the government agency:

> *"Industry has already shown it can rise to the challenge of reducing costs and offshore wind companies are confident they will be cost competitive with new gas and new nuclear by 2025." (F.R6)*

> *"The cost reduction framework is very welcoming [in] that it has proved that offshore wind has a future. We see that the industry is becoming more mature therefore we've got more serious players in and the innovation in the industry has driven cost down especially on the turbine side by having larger turbines that means fewer installations. Because instead of installing 3 MW, we are installing 6 MW for the same power, then it can reduce the number of installations by half. That is the major thing." (SC10)*

The above quote shows that it is believed that cost reduction is achievable and the industry can deliver this aim through investment in new technology. However, development of new technology requires high capital investment which needs future visibility of the market.

> *"The market opportunity needs to be clearly illustrated to these participants to ensure sufficient investment in the technologies which will drive down cost." (D2)*

> *"I think that offshore wind costs are going down but still depend on subsidy from the government. I think it is inevitable that there is a drive from government to try to reduce the costs and therefore competition is the best way to go about reducing the costs. Now the question is: should the developers take the risk of developing projects without having the certainty or knowing that they will actually be able to build it so therefore investing their money at their own*

risk. This is a discussion that is ongoing because this is the system that the UK has adopted with leasing round done by the Crown Estate where areas are basically leased to developers and each developer has to design and consent [their] own project. It is good at one side in terms of the competition, it is not good in terms of risk for developers […]" (P.N2)

"It is uncertain whether the current market conditions will support further long term investment in technology development and supply chain industrialisation. There is limited capacity within the current CfD auction process and little clarity of the market beyond." (D2)

To sum up, the offshore wind market is global and has potential to grow. This provides global players as well as the well-experienced local supply chain opportunity to invest and to compete. The main barrier identified by participants in relation to building a competitive offshore wind market, was uncertainty. The UK government will support the offshore wind market, under condition that the costs will reduce significantly. However, the industry needs confidence and requires long term visibility of the market to be able to invest and to deliver cost reduction. Based on a range of opinions evoked from the interview data, cost reduction in the offshore wind sector is achievable yet requires clarity.

Furthermore, as mentioned by participant (EG): *"there is lots of inefficiencies in the way that offshore wind is managed at the momen"*, and *"they [operators] haven't changed what they are doing, they have just tinkered with bits and tried to iron out some of the inefficiencies in the system."*

This highlights the important role of innovation not only in technology advancement, but in other processes of operation and management of the offshore wind farms which will be analysed in the next section.

4.1.5 Innovation

Offshore wind technology is relatively new compared with other sources of energy in the energy mix, but it has proven to develop fast and it makes up a major part in the current energy mix in terms of generating electricity production. Participants highlighted the role of innovation in different parts of the sector and the role of innovation in technology, and operation and maintenance was highlighted by a majority of interviewees.

4.1.5.1. Technological innovation

Offshore technology has been developed through the modification of onshore technology and transferring technology from the offshore oil and gas sectors. Within this, innovation plays a key role in technological system improvement, from turbine design and manufacturing to foundation and also to escalate the deployment of the offshore technology. So, in order for the offshore wind industry to reduce the costs of energy, innovation is a key driver in each part of the sector. This enables the industry to improve performance and to reduce costs which is the main aim of sustainability transition.

> *"We see that the industry is becoming more mature therefore we've got more serious players in and the innovation in the industry has driven cost down especially on the turbine side by having larger turbines that means fewer installations. Because instead of installing 3 MW, we are installing 6 MW for the same power, then it can reduce the number of installations by half." (SC10)*

> *"Offshore wind is much more rapid innovation in the technology and the commercial models the technology innovation that goes with that. So, we are seeing a very, very quick succession of new products, bigger turbines. The industry standard a couple years ago, was a 3.6 – 4 MW turbine, the standard now for planning purposes is a 5 MW, 6 MW, 7 MW turbine, and who knows in the next few years will start seeing 10 MW turbines coming out to the development. And that is the direction of travel for this industry, bigger turbines, bigger blades, swept area of blades more efficient, power station offshore rather than large numbers of turbines we will see a smaller number but greater*

capacity. And that's going to be always thinking of natural evolution of the industry." (En.L2)

"One of the things that is happening is that turbine sizes and output is increasing which is good because in theory you would therefore need fewer towers, fewer individual sets of foundations, so your cost is going to come down. The downside is that if one of those turbines goes out of production you lose far more of your potential energy production." (En.L1)

A range of interviewees believed that innovation in technology improvement plays a key role because the industry becomes more mature and stabilises, so they are able to reduce the costs of technology and energy. However, there is a negative side to larger turbines. Although the larger turbines mean less installation, there would be significant electricity loss in the event of turbine break-down. This requires more innovation in maintenance which emphasises the effective role of information.

"One of the big barriers to being able to save money is having the proper intelligence to understand when you should be going out to service offshore turbines and when you shouldn't be. And a big part of that is to do with the weather and being able to get proper information that gives you live ideally, or accurate forecasts. That information is absolutely key to making the right decisions about when you are able to safely take technicians out of the field so that you can operate. Because obviously, taking an example, if you make that wrong decision and you travel out to the field and you get there and you can't do any work you've just thrown away all of that fuel that you've used to get out there." (EG)

Information plays a key role to deliver innovation. For example, information in data management is essential which links to save time and capital.

"At the moment most operators of offshore wind farms pull different information from lots of different areas. So they pull the weather information from one place, they pull subsystems that allow them to track personnel from another place, they pull intelligence on what the vessel is doing and how much fuel they are using on the vessel from another place. Obviously that adds extra cost when you are subcontracting all of these things from different places so to be able to

incorporate all of that into one system is one way that people will be able to save money and make stuff more efficiently happen." (EG)

"That's essentially where I see my role, I am helping develop this system (OWMS) which will provide an integrated solution to operators of offshore wind farms to be able to manage all of their assets, manage their vessels, manage their personnel and manage their operations more cost effectively." (EG)

The 'innovation' theme sparked a wide range of opinions; therefore, the respondents indicated the importance of innovation in different parts of the sector.

"The core technology, it is above the water line. So looking at the turbine technology, looking at the performance and efficiency with blade technology with generation technology, they're kind of common areas. There has been a lot of focus around improving reliability of the turbines, improving reliability and integrity of substructures and foundations, improving the installation methods, looking at monitoring seabed conditions, so we can develop substructures and cables and protection systems that mitigate the need for or mitigate scale and pad and other things. So whole variety of different areas that the industry is being learned from." (C.L2)

"There is a range of different innovations, so Scroby Sands which is one the first offshore wind projects in the UK has been trialling a different form of scour prevention maps, you can recycle tyres, it has been piloting a whole range of new innovations to improve maintenance and reduce costs of maintenance for each wind farm." (C.L1)

"With having Scroby Sands in the water for 11 years. It is eleven years old. So it is not even a teenager yet, but it is learning lots, lots of interesting lessons about cables, about maintenance programmes, the cable connection termination points, and blades, and the impact of blades, the impact of generation, the impact on lubricants and oils and everything else. All of that learning is being shared across the industry. So everybody can look at incremental innovation within components and subsystems that inevitably is driving down the cost because things are getting better and getting cheaper and becoming more efficient. Therefore, if they will [be] more efficient, [there will be] less maintenance etc. etc. now that's incremental innovation." (C.L1)

4.1.5.2. Innovation in operation and maintenance

An important role of innovation is to reduce the cost of energy. Maintenance is one of the areas where innovation can drive the cost down. Form a wider perspective, innovation in offshore wind will enable bigger turbines to operate in deeper water and at further distances from the shore, but this needs to be considered in terms of maintenance. There are potential areas for further innovation to reduce timings that are vital for maintenance; one of the key areas is to transfer engineers and technicians to the field. There are some solutions such as building floating hotels for crew and heli-workboats or wind turbine helipad for transferring crew which emerged from the interview data.

> *"One of the key issues relating to that [maintenance] is that you can end up with engineers not being able to get to a turbine because the waves are too great for many days. (...) So one of the major issues with this is how are we going to do that [maintenance] and in some instances, some wind farms have boats and they also have a helicopter and some of these are being serviced by a helicopter." (En.L1)*

> *"There is still room for innovation because we haven't solved all the problems yet, there are still issues about getting staff to site to do the technical work." (C.L4)*

> *"The innovation will be about saving money and time and it will be always need to save money and time, so it always need to be innovation (...) operations and maintenance, is much about maximising the efficiency to get the electricity at the best rate (...) develop boats that can work close to shore [...] having floating hotels, they start using helicopters (...) there is innovation in delivery." (P.L2)*

There are areas that have potential for improvement. It was noted by participants that transferring maintenance crew is a major area in maintenance that can be targeted to reduce time and costs. There are some good examples of using innovation in maintenance such as helipad that is used in Greater Gabbard.

> *"Greater Gabbard, was the first and still really is the only offshore wind project to use helicopters for offshore access, for personnel transfer and no other offshore wind project is using helicopters." (C.L1)*

However, the weather and sea conditions have a huge impact in transferring engineers and technicians to the field which remains an issue.

> *"One of the major issues with this [maintenance] is how are we going to do that (...) And there is a debate going on – do you build platforms out there, accommodation platforms and you fly people out there and back again. Do you have big vessel flotels, floating hotels, which you moor there during the Spring and Summer months and fly your people out to them and they have accommodation there and they go out and service during the summer months, and the debate is still being had about this." (En.L1)*

> *"(...) the difficulty is there that if you take four or five engineers out there in a quite small boat and they get bashed around all over the place – they are not sailors, they are engineers, so they are not used to sea conditions either. So they are being sick, they are ill, they have maybe got to take a three hour journey there, a three hour journey back, and then a lunch break and when are they going to do any work. And by the time that they get out there they are so ill that they can't really work anyway." (En.L1)*

An innovative solution has been developed to address this issue, which emerged from interview data.

> *"The other area we are looking at, interestingly, is with Forces personnel – particularly the Royal Engineers. So people coming out from army, navy and air force, and reskilling them to work offshore because these people are very used to being told what to do and do it and they are used to working in harsh conditions, they are used to working in dangerous conditions and dealing with awkward arms and armaments and things like that. So it is very easy to retrain them to think about gas or oil or electricity or those kind of things because by the very nature, what they have been used to, has been dangerous. And they are used to working away from home – so from all those perspectives they tend to fit in very, very well into the energy sector quite quickly and can acclimatise quite quickly into it. So we are doing a lot of work with personnel coming out of the armed services." (En.L1)*

In summary, innovation is a key contributor to achieve the overall objectives especially in terms of reducing cost of energy and also in terms of speeding up the deployment of offshore wind projects. Furthermore, innovation is a key factor which leads to increase of savings in the energy system through efficiency improvements (for example, re-skilling and re-training programmes). So innovation will be a driver to transform the energy system. Since participant (En.N3) commented: *"innovation should be and has to be at the core of the sector and the core activities as well."* Further to that, taking two examples: data management and the re-skilling programme, show the importance of collaboration across the sector which facilitates the commercialisation of innovation within the technological system.

4.1.6. Section summary

The aim of this section was to provide an understanding of how technical and non-technical factors are implicated within the development of offshore wind energy. The section first identified these multiple factors to analyse the effects that can be brought together to develop the offshore wind system. The findings demonstrated that the UK has potential for the development of offshore wind energy due to natural resources and locations. Also, it was evident that offshore wind is a key part of the UK energy mix and its development is feasible for transition to a low carbon electricity system. However, the offshore wind industry faces barriers to its development. The main barrier that emerged from the interview data was lack of certainty in policy support instruments such as subsidies. This affects the long term view of the market for the industry so it has an effect on investment in the offshore wind projects.

The other influential factor that affects the development of offshore wind is that the cost of this new technology is relatively high. Findings show that there are some areas that can be improved to reduce the cost of technology. This highlights that a transition starts with transferring mutual technology and skills from other offshore industries and eventually improving these to a more specific, standardised and industrialised offshore wind supply chain. The other main area that emerged from the data was innovation and improved technology in different parts of the offshore wind sector. For example, the use of bigger wind turbines in farther and deeper water where the wind speed is higher will increase electricity production. However, this development requires further R&D and incurs additional costs for operation and maintenance.

These inter-related factors highlight that the transition to a low carbon electricity is potentially achievable through the development of offshore wind, when offshore wind system achieves the efficiency levels and sizable market to reduce costs and therefore attract further investments. The themes that emerged from the interview data summarised in Table 4.5.

Table 4. 5 Summary of the emerging themes

Theme		**Sub-theme**	
Natural resources	History	Historical evolution of the offshore wind growth	
	Location	The importance of location in developing offshore wind	
	Demand and growth	Evolution of the electricity market	
Energy Policy	Contract for Difference	Subsidy through the Contract for Difference	
		The effect of Contract for Difference on offshore wind investment	
		The effect of Contract for Difference on industry confidence	
The offshore wind supply chain	Capability of the current supply chain	Transferring technology	
		Transferable skills	
		Specific skills	
		Standardisation in the local supply chain	Networking and collaboration
			Continuity projects
			Joint projects
			Sharing best practices
		Industrialisation of the offshore wind supply chain	
The offshore wind market		Long term market visibility	
		Cost reduction	
Innovation		Technological innovation	
		Innovation in operation and maintenance	
		Innovation in re-skilling and re-training programmes	

4.2. Research Question 2: Socio-technical transition processes

The previous section explored multiple factors that affect the development of the offshore wind system within the UK electricity system and also investigated the systematic interactions between those factors by taking actors' interpretations in characterising the offshore wind context (technology and institutions elements). The current section includes a broader selection of participants from a wider context, such as national and international developers and energy industry, market players and societal organisations at national and EU levels. This section explores the effects of the development of offshore wind as a technological system on socio-technical transition processes.

The main objective of this research is to understand the role of the offshore wind system within the processes of transition. This research explores the interaction between social actors (and their influence) and the effects of offshore wind development within the processes of socio-technical transition. In this part, however, focus is more on interactions between socio-technical systems: the existing electricity system and the offshore wind system. Therefore, in this part the MLP framework is a more appropriate approach than the actor-centric/ constructivist approach (SCOT). In so doing, the interaction between the current electricity system as the established socio-technical system within the energy regime and macro factors at the landscape level and the development of the offshore wind system from key involved actors' perspectives will be analysed. The multi-level perspective framework provides a broad lens onto the analysis of interrelated system change by analysing the interactions of the three analytical levels (niche, regime and landscape).

Therefore, this section aims to answer the second research question: 'how are the socio-technical transition processes within energy regime affected by offshore wind development? What are the effects of the interaction between levels in the socio-technical transition processes on sustainability transition?' To answer these questions, the multi-level perspective framework is employed. According to transition theory, transitions only occur when developments at niche, regime and the landscape link up and reinforce each other (Verbong and Geels, 2010). In order to understand the processes of transition within a socio-technical system (which is the outcome of interactions between key actors, institutions and technology), this section aims to illustrate the effects of the development of offshore wind energy as a technological system, on the UK electricity system.

Therefore, this section is divided into three sections: the first part critically analyses the interaction between the offshore wind system and incumbent energy regime. The aim of this part is to see how the development of the offshore wind system and the current electricity system interplay with and influence each other. The second part analyses the effects of macro factors at the landscape level (for example: EU targets for climate change, economic conditions) on the incumbent regime consisting of institutions: energy policy, for example: RO and CfD. This part also analyses the influence of these interactions (regime- landscape) on the development of the offshore wind system. The aim is to see the effects of these interactions on the offshore wind development into the energy mix and being competitive within the UK electricity market.

The final section then brings the analyses together to evaluate how the interactions of the niche, regime and landscape levels bring opportunities for the development of the offshore wind system and growth in the sector. This interaction is focal to understand the processes of transition occurring in the electricity system and the effects of the development of the offshore wind system within them. This also provides an overview of the offshore wind system to map it as a socio-technical system within the UK energy regime. This contributes to the transition studies literature and opens an avenue to a new perspective of transition studies.

4.2.1 Offshore wind development and the electricity system

The aim of this part is to understand the interaction between development of offshore wind energy and the current electricity system. This part, therefore, builds upon the outcomes of the section 4.1 which characterised the offshore wind context in five main elements: market, policy, technology and innovation, the supply chain, and natural resources. In fact, this information provides a platform for a deeper analysis of the challenges that the offshore wind sector faces in the electricity market. Also, this information is important to understand the interactions between niche- and regime levels.

The development at the niche level builds up internal momentum to advance into the mainstream market. This occurs through learning process, price and performance improvements, and support from powerful groups (Geels and Schot, 2007) who are mainly active regime actors. Transition studies scholars and the MLP school believe that the learning process is an essential indicator for creating momentum at the niche level (Geels and Kemp, 2007, Kern, 2012, Verbong and Geels, 2010). For the offshore wind to be part of the UK energy mix and to gain stabilisation in the mainstream market (electricity market) through creating *'stronger linkages'* with regime elements (Geels and Schot, 2007), it is vital to identify key indicators that increase productivity and improve capability.

The challenge of a new technological system to be part of the incumbent energy regime is that the new technology is mostly expensive which affects the cost of energy production in the energy market to compete with established technological systems. Therefore, for a young technological system to enter the mainstream market and to compete with established systems, the most important challenge is to reduce the cost. Data shows that, for the offshore wind system *"in order to maximise the size of the industry"* (D1), it is also important to reduce the cost of energy (section 4.1.3). To reach the affordability target, DECC urged that *"offshore wind should reach a Levelised Cost of Energy (LCOE) of £100/MWh by 2020" (D1).* This puts forward a further challenge for the offshore wind sector.

With respect to the cost reduction pathways, the Crown Estates foresees opportunities to reduce the cost in two main areas: the *"top technology innovation"* which refers to 6MW class turbine, and in *"supply chain efficiency"*. Drawing on input from the interview and field data, the supply chain is the most important key area to address the cost of energy and the development of offshore wind. The role of the supply chain in reducing the cost of energy is also highlighted in government agencies' documents (for example D1 and D7, section 4.1.3). Therefore, based on data the more the supply chain becomes standardised, the more the cost of energy can be reduced. Participants suggested different ways that the offshore wind supply chain can improve capability (become standardised through performance improvements). So this part analyses different factors that influence the supply chain capability to reduce the cost of energy, which emerged from the interview data.

This part illustrates the links between the outcomes of inductive themes which were analysed in section 4.1 and those themes that draw from transition theories. In doing so, through these themes the challenges and opportunities of the key uncertainties that the offshore wind sector is facing will be analysed.

The first theme that comes up from the transition studies literature and also highlighted by participants is to rely on learning through experience. The learning process is understood in this study as experiments within the offshore wind sector to improve capability (standardisation) through innovation towards stability (industrialisation) and price improvement.

4.2.1.1. From experiment to stability

Participants indicated that learning through experience is one of the important indicators that affect the cost of energy. Because learning processes provide the offshore wind supply chain with the opportunity to improve their capability which in section 4.1.3 was highlighted as ‘standardisation of the supply chain’. Therefore, the offshore wind supply chain can standardise by learning from practices and experiences. Within this theme and based on interview data, experience is one of the main elements that is widely suggested by participants.

History shows the evolution of offshore wind technology and the role of human action in shaping it (section 4.3). Offshore wind farms have largely benefitted by the transference of technology, experience and practices from other fields such as marinised onshore wind turbines and the oil and gas industry (D1).

> *“Wind industry is not new, we’ve been doing for centuries, hundreds of years in the UK but very different reasons, onshore windmills to pump water and grinding wheat […] Onshore wind for power generation yes 20-25 years is one of the most mature technologies[…]But offshore wind turbine might look the same, it is completely different technology.” (En.L2)*

> *“The early days very first offshore wind turbines thought that could take onshore technology and to put it in the water. You cannot do anything further. Because it is a marine environment [with] salted conditions. If you don’t marinise the technology then it doesn’t work.” (C.L1)*

"It is a new industry. It's got rotating machinery in very aggressive marine atmospheres and the whole engineering behind it is still relatively new." (SC4)

As seen from the above quotes, the offshore wind technology has been improved through learning by experience. These learning in practices are used to improve technology to specific products that are designed for offshore wind and to improve the supply chain performance. So these learning processes provide opportunities for the supply chain to *"reduce cost of operating"* and *"to increase power generation" (D1)*. This highlights the importance of technological innovation as part of the learning process to improve standardisation (enactment) and to increase production accordingly.

4.2.1.1.1. Experience through technological innovation

Technological innovation is a key contributor for the increase of production. The industry will be able to improve performance and reach standardisation through commercialisation of technology. In the case of offshore wind technology, the main focus of technological improvement is on manufacturing and commercialising large scale and high performance wind turbines. In this study, high performance refers to larger wind turbines with higher reliability and energy capture, and lower operating costs, as identified by the Crown Estate (D1). Technology needs to improve fast, as the industry is increasingly asked for higher electricity production.

"That is not about squeezing prices down to the safest things it's about being innovative, it's about new commercial models, new maintenance models as well as new technology itself." (C.L1)

The main focus of technological innovation in offshore wind sector is to commercialise large scale and high performance wind turbines. This leads to a reduction in the number of installations and maintenance, which should contribute to reducing the cost of energy. Innovation creates momentum for new technology to improve and to develop.

"In business, innovation often results when ideas are applied by the company in order to further satisfy the needs and expectations of the customers." (F.O4)

"So we have to go beyond the experiences of oil and gas and actually take new ways of thinking, new ways of developing, new ways of servicing and new ways

of operating that were never felt to be a good thing for the oil and gas sector. So for me you have to throw the oil and gas rule book out of the window." (C.L4)

The offshore wind sector has been operated base on combined experience transferred from onshore wind (section 4.2.1.1) and offshore oil and gas sectors (section 4.1.3.1). As explained, the engineering models for offshore wind technology are different than for onshore wind. The UK offshore energy industry has long term industrial experience in delivering large scale oil and gas projects which has been largely transferred to the offshore wind sector through the supply chain. The offshore wind supply chain needs sufficiently standard models and methods for delivering the new technological system in order to grow, to deliver large scale projects and to be part of the energy industry through competition.

In terms of technology, the offshore wind supply chain has strength in four main segments: *"cables, electrical systems, installation, and operation and maintenance" (D5)* which are also the common areas within the established oil and gas industries.

> *"When people talking about the offshore wind supply chain, you can't say here is a list of companies […] because there are very, very few and far between the companies that 100% focus on offshore wind. Some of the more successful companies are 50-50 with another industry whether it's be marine, or maritime, or defence, or oil and gas, or aerospace, and offshore wind is a part of that business." (C.L1)*

> *"[…] offshore wind farms have largely used products adapted from application in other fields, for example: marinised onshore wind turbines and foundations designed using oil and gas industry standards for manned platforms." (D1)*

Experience through different aspects provides a solid platform for the offshore wind supply chain to reach at standard level of efficiency. Some aspects of technology are transferable from the fossil fuels industries (section 4.1.3.1), including: *"project management and development, turbine supply, balance of plant supply, installation and commissioning, operation, maintenance and service (OMS), and support services" (D4).* Furthermore, high performance wind turbines need high levels of innovation. Therefore, whether the technology is transferred or designed specifically for the offshore wind sector, it needs to improve and become standardised and the role of supply chain is important. Improvement of each element is necessary and technological innovation and the standardisation of the supply chain is interdependent.

4.2.1.1.2. Improve standardisation through innovation

Standardisation of the supply chain is widely understood to increase the efficient use of resources. It is evident from data that: *"an innovation, an idea must be replicable at an economical cost and must satisfy a specific need" (F.W6).* For example, large scale and high performance wind turbine and jacket foundations are technological advancements that can deliver more production in deeper water and a greater distance from the shore. Also innovation *"involves deliberate application of information, imagination and initiative in deriving greater or different values from resources, and includes all processes by which new ideas are generated and converted into useful products" (F.W2).* Translating this quote into the processes of standardisation of the supply chain, indicated that innovation enables the supply chain to decrease the cost of electricity production through the solving of the inefficiencies within the sector. For example, it emerged from the data that operation and maintenance is one of the strength segments of the offshore wind supply chain and should be the main area of focus to reduce cost.

> *"There are lots of different ways of improving and making things more efficient. So making the turbines bigger you need to put less of them in, changing the technology what we are doing is looking at the operations and maintenance side of things and managing all of the personnel, fuel use of the transfer vessels." (EG)*

> *"The innovation will be about saving money and time and it will be always need to save money and time, so it always need to be innovation […] operations and maintenance, is much about maximising the efficiency to get the electricity at the best rate […] develop boat that can work close to shore […] having floating hotels, they start using helicopters […] there is innovation in delivery." (P.L2)*

> *"One of the things that is happening is that turbine sizes and output is increasing which is good because in theory you would therefore need fewer towers, fewer individual sets of foundations, so your cost is going to come down. The downside is that if one of those turbines goes out of production you lose far more of your potential energy production. One of the key issues relating to that*

is that you can end up with engineers not being able to get to a turbine because the waves are too great for many days […]" (En.L1)

In line with technological advancement of operating larger scale turbines in the offshore wind farms, maintenance of the sites is also vital. Although bigger turbines means there will need to install fewer turbines, it also means deeper water sites that are farther from the shore. This requires more time to transfer crew (engineers and technicians) to the site for regular service and necessary maintenance of turbines to avoid production loss.

"One of the big barriers to being able to save money is having the proper intelligence to understand when you should be going out to service offshore turbines and when you shouldn't be. And a big part of that is to do with the weather and being able to get proper information that gives you live ideally, or accurate forecasts for that information is absolutely key to making the right decisions about when you are able to safely take technicians out of the field so that you can operate. Because obviously, taken an example, if you make that wrong decision and you travel out to the field and you get there and you can't do any work you've just thrown away all of that fuel that you've used to get out there." (EG)

"What people [windfarm operators] have learnt and people have built specialist equipment for that market, that has brought the cost down and that has brought the deficiency down." (SC2)

"That's essentially where I see my role, I am helping develop this system which will provide an integrated solution to operators of offshore wind farms to be able to manage all of their assets, manage their vessels, manage their personnel and manage their operations more cost effectively." (EG)

It is evident from the interview data that the supply chain becomes standard through a number of elements within learning processes as explained, such as sharing experiences, practices and skills. Data shows that learning processes have a major effect on the development of especial skills and experience in response to the offshore wind supply chain demand to increase the level of production and productivity. These learnings are collectively improving the supply chain capability to the standard level in which it becomes stabilised within the electricity market and a part of the energy mix. Also, the interview data illuminated that technological innovation and innovation in the efficient management of the offshore sites and operation largely affects the production, which consequently has an effect on the cost of energy through the standardisation of the supply chain. These elements collectively drive the cost of technology down which is the main aim of sustainability and the affordable cost of energy.

> *"There is a huge requirement for the industry to innovate to get the costs down across the supply chain. There is a lot of innovation going on to achieve that- we are seeing obviously turbines just becoming bigger and bigger and they are going further out to sea, they are looking at floating platforms now, we are seeing a lot of smaller innovation in terms of operations and maintenance and it is all with the purpose of trying to bring the costs down within the sector." (En.N4)*

> *"We've seen some cost reductions, we've seen lots more innovation coming into the market. So we are seeing larger turbines which have greater energy capture, there are fewer structures, we are seeing cheaper foundations, we've been able to install faster and therefore cheaper, a lot of the lessons learnt. So there are lots of things, that are beginning to happen to help bringing down the cost." (SC9)*

> *"Offshore wind in particular, I have been able to manage that, has certain challenges because sampling what the atmosphere is doing, what the ocean is doing, out at sea, is much more challenging than it is on land […] unless you can do that, you are going to be providing inaccurate information that is going to cause cost inefficiencies for people trying to operate." (EG)*

It was explained that the offshore wind industry is young and the supply chain is mainly formed by transferring skills from the established fossil fuels sectors within the energy industry (section 4.1.3.2). It was analysed that the offshore wind supply chain; however, can improve through a number of learning processes towards increasing the level of productivity and standardisation. These learning processes influence the cost of energy (section 4.2.1). For the offshore wind industry to be part of the energy mix and to be able to compete with the other sources of energy in the electricity market, a standardised offshore wind supply chain is needed. These elements along with other elements (which will be analysed in section 4.2.1.2) are collectively operationalised as the processes of stabilisation of the offshore wind supply chain, as illustrated in Figure 4.3.

4.2.1.1.3. Standardisation through sharing experience and continuity

From the interview data two key elements emerged: continuity and sharing best practices are also effective in order for the offshore wind supply chain to be stabilised. These are key elements in learning processes for the supply chain to fulfil its capability and compete in the electricity market. Furthermore, these elements are key for the offshore wind supply chain to link with the established energy industry and to build common projects. It is evident that the offshore wind supply chain is *"immature and operates on a project-by-project basis" (D1)* so experience of doing a number of projects with the energy industry (incumbent firms) allows the supply chain and the industry to be more productive and to respond better to the market. Also, continuity of doing projects provides the industry with the opportunity to use resources and assets more effectively through learning lessons from past projects and by mitigating the risks of failure. This results in more efficient use of resources and consequently reduces costs.

> *"We did our mistakes from [operation of our first offshore wind farm] but we have learned from that. And we have implemented all the good examples from the [our first offshore wind farm] onto that. Of course we improved our mistakes." (SC11)*

> *"It's also just the lessons learnt with people, so at [our company, developing, operating] we tend to build one project, then move on to the next project then the next project. So all the lessons learnt on one project, we take all of that, we implement all of that best practice and lessons learnt on the next project. But of course if we end up with gaps then you lose the people and all the knowledge transfer and then when you are on your next project you make mistakes again and they cost money. So for me it is about having a nice continuous stream of projects, one after the other, to keep the lessons learnt, the best practice, the people, flowing from project to project. That certainly helps us I think." (SC9)*

> *"With having Scroby Sands is being in the water for 11 years. It is eleven years old. So it is not even teenager yet but it is learning lots, lots of interesting lessons about cables, about maintenance programmes, the cable connection termination points, and blades, and the impact of blades, the impact of generations, the impact on lubricants and oils and everything else. All of that learnings is being shared across the industry. So everybody can look at*

incremental innovation within components and subsystems that inevitably is driving down the cost because things are getting better and getting cheaper and becoming more efficient. Therefore, if they will [be] more efficient, [there will be] less maintenance etc. etc. now that's incremental innovation." (C.L1)

Continuity and experience also increase the efficiency and decrease errors and mistakes which are essential elements for the offshore wind supply chain to be standardised, that affects the cost of energy as well. This enables the supply chain to deliver cost savings.

"The continuity allows everybody to get better, it allows you to invest in the market, invest in better equipment, invest in better ideas, do the research and development." (SC2)

"We are now seeing projects where the biggest problems on the first windfarms were cabling. Most cable-led projects are now either finished on time or ahead of time. Why? Because the companies are now familiar with the process so they've got better at it, as they have got better at it they become more efficient, as they become more efficient the cost comes down. So it goes like that. And that's continuity… the more you do the better you get." (SC2)

Sharing best practices between the offshore wind supply chain and the established energy firms increases the number of common projects, so increases continuity of doing further projects that leads to stabilisation of the supply chain (performance improvements). Therefore, within learning processes, these three themes: standardisation, continuity and sharing experience are linked. Also, sharing information and exchanging knowledge and practices between academia and industry are also evoked by a range of opinions from the academic and industry participants.

"Industry always has to pay attention to the financial bottom line. Academics still have some scope for following research to see where it will lead. Sometimes this provides useful insights for the development of technology." (AC2)

"We are currently running apprenticeship schemes which help people get into the offshore gas and renewables industries. That is something that has been very important to us. We need to be able to call on that workforce and for it to actually grow and we want people to be able to get into the industry and make a job for life really." (SC14)

One of the areas that sharing practices is beneficial for improving both supply chain and the industry capability is to create effective relationships with academia.

> *"Partnerships should be formed between industry and academia in order that relationships can be established. This is most easily done by industry providing case study support for teaching. This established relationship means that when a piece of research highlights a possible benefit to industry it is much easier for dissemination without suspicion. Without established relationships there are always barriers to dissemination." (AC2)*

Collaboration between academia and the industry can happen in two ways. The first method that was suggested by a participant who is holding a position in a high track record energy firm is to increase involvement of the industry with universities and colleges by offering graduate schemes and apprenticeships. The aim is to encourage students to work with the industry at an early stage of their study. This also has benefits for the industry for providing training in the special skills that are required. The second method that an academic course leader highlighted is to exchange information in order to establish a solid research base collaboration. This can happen when the industry shares its practices.

The data shows that standardisation is essential for the supply chain to reduce the cost of energy and to increase stability in the market. The supply chain can heighten the standard level of efficiency through a number of elements that were explained, such as improving technology through innovation, continuity and sharing experiences. The standardisation level affects the supply chain capability and enactment, qualifying it to move forward and to be part of the energy mix and providing eligibility to be part of the projects that are being auctioned through the CfD.

> *"I think in the UK it helps though to be eligible to bid for a CfD you need a supply chain that has been approved and the supply chain is all about promoting the UK as local content." (SC9).*

Also, there are opportunities for the local supply chain and businesses to be part of the offshore supply chain by sharing their experience and information with the developer in a number of areas as participant En.N4 indicated:

> *"There is a 25 year operations and maintenance requirement which is a huge opportunity for local businesses typically that will be ran out locally: local vessels, local contractors to carry out the maintenance side. There are lots of skills opportunities there and the need for skilled people." (En.N4)*

This indicates that the development of skills and experience increase production and productivity which improve standardisation of the supply chain accordingly.

Therefore, the offshore wind industry gains experience through improvement in key areas such as *"installation costs and timings, turbine availability and operating and maintenance costs" (D1)* when these areas will be better managed across the supply chain. The data shows that within learning processes the supply chain gains experience by collaborating horizontally, such as sharing best practices and information among Tiers of the supply chain that then improve the standardisation. The evidence from the interview data suggests that the offshore wind supply chain has the capability to develop through improvement of a number of elements such as skills, technology (also analysed in sections 4.1.3.1 and 4.1.3.2) and managing resources to become more standard. This enables the supply chain to improve the cost of technology and energy and so become stabilised in the energy market which results in the qualified offshore supply chain becoming part of the energy market. However, there are effects of vertical collaboration with the established energy firms which will be analysed in the following section.

4.2.1.2. The interactions of the incumbent firms and the offshore wind supply chain

Arguably, established energy firms from the energy industry provide opportunities for the offshore wind supply chain. These opportunities can be in the form of sharing best practices, information and experience, and also in the form of joint projects which also heighten the capability of the supply chain towards maturity and decreasing the cost of energy. Development of the local offshore supply chain is included in the analysis of niche level, because the local supply chain is also instituted at the national level in the UK.

However, the offshore wind supply chain requires sufficient financial supports to improve performance and to invest in technological innovation, and needs policy support in terms of market certainty.

In this part, the interactions between established energy industries and the offshore wind sector will be analysed to evidence how regime actors facilitate a new technological system. To have a better understanding of this interaction, in this part, one of the main elements of transition theory that explains the level of supports from regime actors will be employed. The 'support from regime actors' is one of the elements of transition theory which reflects the interaction between actors at niche and regime levels and illustrates the level of maturity of the niche. The aim is to understand the effects of the support by regime actors in order for the niche to develop into the regime and to become part of the regime.

To do so, the interactions between regime actors and niche actors will be analysed, which continues the discussion from the previous section (4.2.1.1). The focus here is more on the support that is provided by regime actors for the offshore wind supply chain to become part of the UK electricity market. The regime actors in this study include: energy industries (incumbent firms) and investors (public and private). Based on the transition studies literature and evidence from the interview data, the offshore wind supply chain requires support from regime actors to become part of the energy regime and provide a platform for technological innovations to improve the cost of energy.

As evidence evoked from the interview data and explained in the previous section, these supports can be in the form of sharing experiences and practices, information, and skills. In line with previous sections, these interactions consist of sharing best practices and experience in the form of joint ventures, and joint projects collaborating with the energy firms within the supply chain (vertical collaboration) which will be analysed in the following section (4.2.1.2.1). The energy industry, however, can also reorient and form their assets such as transferable skills and technology so as to improve their capacity which will be analysed in section 4.2.1.2.2.

Section 4.2.1.2.3 will analyse the effects of the investment supports on the development of offshore wind energy. It is evident that public subsidy through CfD provides some levels of certainty for both the offshore wind supply chain and the established energy firms. The certainty is also important for the investment and inward investment for technological development and on projects. The investment is a fundamental element for accelerating the commercialisation of technology to the mainstream market.

4.2.1.2.1. Joint ventures and joint projects through sharing experience and best practices

Energy industries in this study refer to those large energy firms who have long term track records in energy supply and established market positioning. These firms have experienced of supplying energy from other sources of energy, mainly oil and gas, while they also enter into renewables projects. Energy firms have resources such as skills, experience and commissioning technology which can be transferred to the offshore wind sector.

> *"The oil and gas industries have matured over several years and have developed strategies. The wind industry is still developing the strategy for doing it. There are a lot of best practices in place already and we take the view that why you don't make use of what has already been done for other sectors. The challenges are much the same. You are building expensive items at sea in harsh weather environments." (SC1)*

> *"What we have tried to do at a very early stage is to engage with the supply chain. So we have a supply chain event where we invite all the local businesses, all sorts of very small local businesses, larger businesses, to come along to understand about what we are doing what the development is, what the opportunities are. […] we really do try and encourage our main contractors to engage with the local supply chain and for those sub-contracts." (SC9)*

Through the long term established market positioning, the energy industry in addition to technology and assets, has solid experience and useful lessons which are transferable to the offshore wind projects. It is evident that the energy developers have interests to invest and to increase the level of involvement of the local supply chain through the *"supply chain event"* that participant (SC9) mentioned. This is some sort of support that the offshore wind supply chain can receive from the regime actors.

Within these themes, joint ventures and joint projects are other elements in relation to the support to develop the supply chain that are widely recognised by participants. Data shows that the energy industry can form some level of support to the offshore wind supply chain by doing projects jointly.

> *"I think there are lots of things most developers do to really try and engage with the local supply chain to make them aware of what is going on and encourage our main suppliers to do business with them. So we can facilitate these discussions, we can put people together and we can encourage our tier 1 suppliers to do all they can to maximise the local content." (SC9)*

> *"At the moment we are working more with developers in Tier 1 to connect those opportunities within the supply chain and that is working reasonably well. We have had for example through [developer], an event with them [local supply chain], with [manufacturer] a number of Tier 1's talking about the opportunities and then we have had companies like [bespoke lifting equipment] actually winning contracts for Dudgeon as a result of that. So that, that is starting to happen. Companies are starting to win business within the UK especially at the lower tiers." (En.N4)*

> *"With those companies forming joint ventures and creating that competition I think that is only good for the sector as we move forward. I think it is really good for competition that the companies are forming joint ventures and bringing a much more competitive commercial offering to the market." (P.N5)*

Collaborating integrally with all Tiers of the supply chain enables the industry to accelerate projects. This will help the offshore wind supply chain to gradually improve capability and gain stability in the market.

> *"We haven't seen it [joint ventures] yet but I think the same sort of thing is going to happen in the foundation side of things. So on the jacket foundation side for example there are three or four projects coming up before 2020 including East Anglia [ONE] that require jackets and there aren't the suppliers in the supply chain. There isn't a large enough supplier that can deliver all of that, that can cater for all that demand. So it is very likely that in the foundation*

side we might see something similar in the consolidation of companies forming joint ventures in order to provide their supply." (P.N5)

"The model which is being used more and more in the industry is one of partnering. So developers are now partnering with either other developers or other investors, strategic investors or financial investors, to share that cost." (SC9)

The above quotes show that, forming joint ventures within the offshore wind sector is shaping the generation of assets by growing the number of vertically integrated partners and parents such as developers, strategic and financial investors. This strategy can enhance both the industry and the supply chain's capability and readiness *"[...] to hold a full technical understanding of their technology and quality [...]" (D17)* to compete in the electricity market. This can also add value to the UK centralised electricity system. The forming of joint ventures and projects through the vertical integration strategy brings advantages for the industry, while the supply chain is capable to do projects through standardisation improvement.

4.2.1.2.2. The energy industry reorientation through complementary assets

The UK energy system for electricity production has been largely operated by a few large firms which are fossil fuel and nuclear based. These firms have assets and resources such as skills and technology through a long term market established positioning.

"If you look at the utilities, the developers, the operators, [...] it is a lot of the oil and gas operators and developers, that are the investors the offshore wind, people like E.On, RWE, Centrica, and even Dong, Vattenfall, Scottish Power, and Scottish Power Renewables, they are not investing not just in offshore wind, they are operating oil and gas fields, they are operating nuclear power stations, they are operating biomass power stations, gas fire power stations, onshore renewables, and they also do offshore renewables." (En.L2)

"It's the supply chain, it's the businesses that are delivering those projects and there is very few businesses that are in one solo or one particular area. They all have a very diverse portfolio. But they have diverse activities across oil, gas,

decommissioning, nuclear, the offshore, onshore wind whatever they might be. They are engineering businesses that are key to the multiple sectors." (En.L2)

"Those who investing now, which have oil and gas interests, look at the rest of their portfolio, they already have electricity generation projects, they have biomass projects, or gas fire power stations, so they're not only producing gas, they're producing gas fire feeding their own power station, which is selling electricity, they understand those markets. […] What is the sell differences in business unit they understand, as parent company, they understand the differences between the markets and so they are enable to interplay between them." (En.L2)

Data shows that there is a trend towards investing in renewables within incumbent energy firms. Since these firms have long term market established positioning, this advantage enables them to invest in renewables through their assets and resources and to improve their capability in renewables through their understanding of the electricity market.

"I think certainly it is going to be very tough to develop offshore wind in a large scale offshore environment without taking lessons from oil and gas. [xxx]'s background started off in offshore oil and gas and has actually moved into offshore wind but we still work in both. But actually about 70% of our turnover comes from offshore wind nowadays and I think what we have done and other people have probably lacked, we have taken some of the mind-set of oil and gas some of the common sense and some of the health and safety mind-set and taken that into offshore wind." (SC14)

This provides opportunities for the energy industry to reorient their assets and to improve the incumbent technology towards the offshore wind industry and towards low carbon electricity production. Investment can be made into the offshore wind market through complementary assets and resources. Because operation and generation require high capital costs, this encourages developers, who are predominately fossil fuel based, to maintain their assets and improve incumbent technology within their resources. For example, commissioning offshore oil platforms is similar to offshore wind, in terms of engineering applications, technology and resources. Also, as analysed in previous sections, skills are common and the skilled workforce are transferable to some degree to the offshore wind sector.

"As far as skills are concerned, what we are seeing is that a number of developers are actually putting aside a budget to develop skills locally. So [xxx], [xxx], [xxx], they all have a community type fund to help develop local businesses and skills." (En.N4)

It is evident that the offshore wind sector is a young industry which is developing within the established energy industry. The offshore wind supply chain, in terms of assets and resources, is relatively under developed. There are therefore opportunities for the offshore wind supply chain to use incumbent energy firms' resources such as transferable resources, assets, skills, experiences, and technologies, to enable development and growth to the sector.

4.2.1.2.3. Investment support

The offshore wind sector's supply chain is considered to be at the niche level, because it has limited assets and resources. Since the industry is relatively new, it is dependent on financial support and supplements for its development. The support can be in the form of investment support and subsidies through the government's policies.

"The future offshore wind it means the trends the offshore wind is growing and growing rapidly. Now it is still a very immature industry and still requires a level of support from the public sector to deal with risks and investments, to create a stable policy framework which will enable investors to deliver projects. It needs the government supports, not necessary subsidy, because the industry now recognises it needs to be cost competitive with other industries. We need to reach parity." (C.L1)

The offshore wind supply chain has relied on subsidies in the early phases of its development. Financial support has been provided under two main schemes, Renewable Obligations and Contract for Differences, administrated by DECC, and explained in section 4.1.2. The subsidy schemes also provide the industry with longer term visibility of the government's ambition to meet the climate change and emissions targets.

"A lot of policy that has come out, from DECC, has been focussed on trying to help boost the supply chain because we have the largest market, we historically have seen limited percolation of opportunities into the supply chain in the UK." (P.N5)

"In the UK typically what's incentivised private companies to build offshore wind projects is long term financial support through government support schemes. So historically that's been done through something called the Renewables Obligation which comes to an end in 2017. And it is being replaced by something called Contract for Difference which has been auctioned this week for the first time. Both those schemes provide very long term financial support so the Renewables Obligation provided 20 years of payments for generation by offshore wind projects and the Contract for Difference provides 15 years of support. So government is providing the financial incentive but it is still for private companies to come forward and take the risk to build the projects, and operate the projects. So long as they do that and they generate electricity, for every unit of electricity they generate they will receive a support payment from government." (M.L1)

The policy support is required to provide the industry and investors clarity of the objectives and to provide subsidies to assist the development and improvement new technology. Although there is support, there are also some uncertainties caused by these schemes as was explained in section 4.1.2.2.

"We are fortunate enough to get Area Assisted Status and that means that some of the percentage grant that we can offer has now been increased for development within that area but it also means that businesses can get some tax relief on their investments within the area. So we are trying to put together a package where we can work with the Tier 1 companies, the main constructors the licence holders offshore so that we can help them get the investment that they are looking for from central government. Once we can hopefully get them to this area, it's those Tier 1 contractors who then provide the supply contracts for the smaller businesses. So what we have tried to do is to work in the background to try to get all that information and support ready for when the Tier 1 contractors come through." (P.L3)

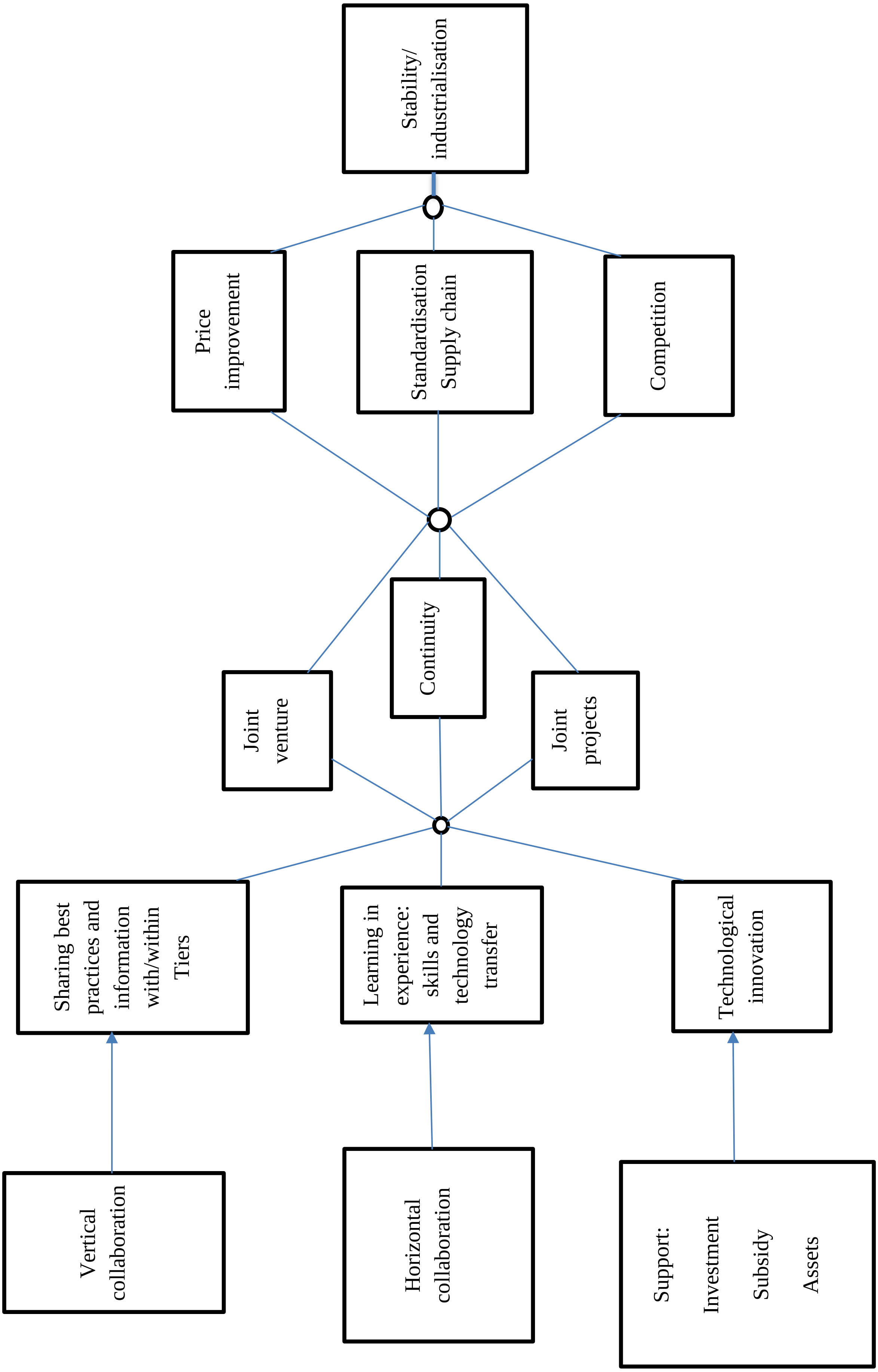
"As part of the funding, we through the Enterprise Zone are able to offer small businesses up to £275,000 worth of rate relief over a 5 year period so that is encouraging them to move in to the area but also through the New Anglia LEP [Local Enterprise Partnership], there are a number of grants that are available to help businesses moving into the area." (P.L3)

Due to the embeddedness of the offshore wind to its location, opportunities for the development are specific to the local area, but the opportunities are also national. Lower Tiers of the supply chain can be brought into the system and local authorities can help them through different investment support schemes that are available at national and local levels. Also, the European Union provide a support scheme available for specific projects within Europe.

> *"The European Union fund is very new for renewable energy projects and we have 3 billion euros to 2020 and this money comes from the fund that is called NER300 (New Entrant Reserve 300 million) allowances under the emission trading scheme […] and the NER300 fund does fund some renewable energy projects but it doesn't fund them entirely but it is only shares funding […] We only fund innovative renewable technology. That is an important word 'innovative' that means that if you have got a standard onshore wind farm using conventional technology there is no way you will get the subsidy from the EU, whereas if you have floating offshore wind turbine- there are such things we are subsidising off the cost of Portugal, floating rather than fixed offshore wind- there is such funding, but small." (I.P1)*

Therefore, for the industry to grow, the supply chain needs to develop and become capable of managing its resources, in line with the investment available. For both the industry and investors, clarity of the policy and objectives are essential. Therefore, the policy theme links with these elements.

Figure 4. 3 The processes of stabilisation of the offshore wind supply chain



Source: Author

4.2.1.3 Socio-technical regime and the development of offshore wind system

The socio-technical regime in this part is characterised by cognitive and regulative rules and the actors from incumbent energy firms. The regulative rules form the regime standard under which the electricity system operates and the landscape plays a role in this context through the impact of macro factors such as climate change. In terms of climate change and energy policy the UK has set several obligations to meet the EU targets.

> *"Climate change act which is law in the UK, we were the first country in 2008 to put into place legal commitment, legally binding commitment UK Climate Change Act and carbon budget cycle.[...] The UK's contributions to those 202020 targets are 15% of the UK's primary energy from renewables by 2020." (P.L5)*

This obligation regulated the energy regime under which 15% of the primary energy is generated from renewable sources. The UK planning scenario beyond EU202020 is to produce 41 GW of energy from renewable sources by 2030.

> *"The DECC scenarios show that 41 GW of installed capacity can be reached by 2030 if annual installation rates remain at about 2.5GW per annum and if 15GW was achieved by the end of 2020. In this scenario, the UK remains the largest European market and will increasingly reap the economic rewards from sustained innovation and growth in services." (D5)*

> *"If policies work, and if we get a true carbon price to reflect things, then it [offshore wind] can be seen as a modifier in how we meet our carbon objectives. In a time of when we didn't respond to climate change and in a time of when we didn't have government objectives to meet and low carbon ambitions, it would look stupid. But in a time when we have to meet them, we need renewable electricity, we need to reduce our carbon emissions, then wind at scale looks sensible. But I think you have to take the long term view." (M.L2)*

Due to the availability of natural resources for offshore wind, the offshore wind system is recognised as a key contributor for the electricity system to meet those targets.

"Obviously the amount of offshore wind on the system is increasing year by year, well, month by month and we have got 5 GW on at the moment and we will have 10 GW by 2020. So it is having a profound effect on the energy mix." (P.N5)

"My calculation, looking at the energy this country is going to need in 2030, I think we will have between 25 and 30 GW of offshore wind by 2030. And that will be providing perhaps 30% of all our electricity and I can't see any other way that the UK is actually going to get its electricity in 2030." (SC5)

The role of offshore wind in the energy mix is becoming more and more important. Therefore, to achieve the ambitious targets set, the industry requires an increase in the degree of clarity in terms of policy ambitions and future market visibility. The role of actors is important to achieve these changes within the socio-technical system where cognitive rules can modify the energy policy and provide the clarity needed.

The socio-technical regime is also characterised by cognitive rules which is understood in this study as all actors' activities within a shared belief system towards meeting the regime regulations. There are some elements that emerged from the interview data which highlight the importance of change in cognitive rules through the shared belief system.

"We still need a very diverse mix of a balanced energy mix, certainly for the UK, we need nuclear power as stable base load, we need large scale solar parks, and again it is part of the energy mix, its rapid growth over the last five years has been absolutely astonishing. Offshore wind will play a much greater and much more significant role in the coming years and decades. As well as other renewables: bioenergy, biomass, biofuels." (En.L2)

For the UK to meet the electricity demand there needs to be a diverse mix of energy. Although the energy policy is regulated to reach climate targets by mitigation of fossil fuels, the policy considers other sources of energy as well.

"I've never seen a policy or a plan that says we want to be 100% renewables. I think that is not achievable and I think that is too risky. I think that is far too much risk by having everything in renewables, because whether it is biomass feedstock and all looking at solar PV and on and offshore wind, the wind doesn't

blow 24/7 the sun doesn't shine 24/7. We need other forms of generation." (P.L5)

For the offshore wind industry, which is relatively new and for the supply chain which is small and immature, there needs to be stability in the electricity market. In section 4.2.1, the elements that affect stability and capability (performance) of the offshore wind supply chain were analysed and presented. The aim is to drive down the cost to make the offshore wind industry (including the supply chain) competitive within the overall energy market. To achieve this, the industry needs financial and policy support and some clarity in terms of future market size, government ambitions and objectives.

"Although the industry itself is bringing the cost down and there is still that interplay between the industry and the government which kind of holds the key to unlocking the future into 2020-2030." (P.N5)

The industry asks for clarity within a belief system where all actors can share their ideas, ambitions and future.

"We hear lots of people talking about certainty. Certainty is unrealistic, we will never have certainty, can't have certainty as an industry, we don't get certainty in any industry. What we want, I think what we are looking for is clarity, clarity of objective, clarity of target, clarity of any achievement going forward and that is what I would like to see. I think from an investor point of view, that's what investors want; they want some clarity of what they are doing. What we are trying to achieve and going ahead." (F.G5)

"We are already doing great things like we are creating jobs, creating manufacturing and creating economic benefit and to carry on doing that we need to push ourselves as a sector and push ourselves as an industry and drive cost down and we need to do that all together: developers, supply chain, manufacturers, government, regulators everyone working together to bring that cost down." (F.G5)

Participants from the energy industry believe that cost reduction is achievable through clarity of the market and the government ambitions of their objectives and targets.

"What they [government] wants to do is to see this coming to an end to see the subsidies tailing off and innovations starting to come through to achieve the levelised cost of production." (En.N4)

The sector is required to reduce the cost of energy and to become stabilised in the market through competition with other sources of energy. There are several frameworks that have been introduced by DECC to reduce the cost of energy and make it affordable, such as the Levelise Cost of Energy, and the Cost Reduction framework.

The interviewees and government documents suggest that cost reduction is achievable by establishing a shared belief system for further collaborations between key actors: industry, supply chain and government.

"I think reducing cost is something that developers work on every day and it is something that takes place within the projects we run - in the way we do the engineering, in the way we do the set up and the design of the project and the way we do procurement. [...] I think the real measures to drive costs down are coming from within the projects and the work that is done there and the use of new technology and all that." (SC9)

"I think it is great time for the industry, regulators, government, supply chain, developers to be sitting down and discussing where we are going next, where we are heading, what it is we want to achieve, how much we want to see come to the system, what kind of renewables we want to see come to the system, how much money we invest to doing that.[...] For one supply chain in this country, they need to see the size, the scale, the future. I think we won't lose some of that if the industry and the government work together, to re-establish we are headed where we want to be." (E.G5)

In summary, the offshore wind industry want to see clarity over cost reduction frameworks and clarity over the size and scale of projects within the given timeframes. These are key aspects for the sector since renewable energy and offshore wind as analysed is a key part of the energy mix to deliver climate and emissions targets, affordable energy prices and security of supply. The offshore wind industry can drive the cost down through a number of elements that have been discussed, such as driving technological innovation, stabilising and standardising the offshore supply chain in the market. These elements collectively enable the industry to drive value and bring down the cost of technology and energy.

4.2.2 The interaction between the development of offshore wind, electricity system and the wider context

This part explores the processes occurring from the interactions of the three levels: landscape, regime and niche. The aim is to analyse the interaction between the regime and the landscape for offshore wind development. The landscape for the electricity system refers to those macro factors that change the electricity regime institutions, in terms of cognitive and regulative rules, and influence the development of the offshore wind system. in the following sections the effects of macro factors at the landscape level on the electricity system and on offshore wind development will be analysed. These factors in this study include political developments and economic trends.

4.2.2.1 The electricity policy landscape: effect of macro-political developments

Global environmental concerns over climate change issues are increasingly putting pressure on the current electricity systems. This leads to a growing recognition of the need for further deployment of renewable sources of energy within the electricity systems. Although the EU proposal of the 2020 targets gives the member states choice to deploy any sources of renewables, the member states are obliged to meet the targets. The UK commitments to the carbon emissions reduction and renewable energy targets have become key drivers of electricity policy. The UK has set policies to promote renewable energies to address climate change issues and to meet the EU targets. The country has an abundance of sources and natural resources for offshore wind and can take advantage of proximity to the market.

> *"Kyoto protocol discussions going on in Paris this year, the global climate change commitment which are looking at the big drivers, the global drivers for change and a lot of that is a big shift from a high carbon economy to a low carbon economy, so moving from oil, gas, petrol chemical, hydro carbons to new alternative sources of energy generation." (P.L5)*

"The commission acts because the member states collectively wanted to act, we were in affect asked to produce national targets for renewable energy, we did suggest that there might be a 20% target for renewable energy in 2020, the commission pre-suggested that in January 2007, the member states had to accept that proposal and when they did accept it we then proposed a directive in January 2008. So the commission thinks renewable energy is a good idea but it isn't something that we can impose on the member states, they must agree and indeed they did agree unanimously. All the member states agreed that in 2020 they wanted renewable energy to be 20% of the final energy consumption." (I.P1)

"The UK has a vital yet extremely challenging target to reduce greenhouse gas emissions by 80% by 2050 compared to 1990 levels, and it is clear that several different low-carbon electricity generation technologies will be needed to deliver this commitment. As part of this transition, the UK is forging ahead with ambitious levels of offshore wind deployment: the UK already has the biggest offshore wind market in the world. This is expected to grow to over 10GW by 2020, and to be a growing part of the energy mix in the 2020s as the UK decarbonises its economy and works to deliver the newly agreed ambitious EU greenhouse gas reduction targets for 2030." (D7)

"We [European Commission] will look at them [member states] whether they are going to meet the target. We watch them very carefully, every 2 years there is a report on how the member of state is progressing to meet their target […] we will have to see whether they remain on track and watching and if they don't, if it is manifestly clear that member states are not doing enough, we in the Commission will go to the European Court of Justice in Luxemburg and take infringement action against them. And the Court could attempt a level of fine on the member states who are found to be non-compliant with their targets." (I.P1)

"European Union tries very hard when it accepts legal obligations and legally binding targets. The member states generally work really hard to meet targets. That is particularly true of the northern European countries like the UK who are proud of having the good compliance record. The UK is not in dying economic circumstances that other member states are, unlike Greece […] but they have same legal obligations, perhaps different target" (I.P1)

The pressure of the EU targets has led to changes in the energy policy landscape. In terms of the energy policy landscape, the UK, as part of the EU has set a political agenda to respond to the carbon emissions reduction and renewable energy targets. The importance of these targets on the UK policy programme effects government subsidies, such as RO and the CfD, in favour of renewables, even though there has been a period of economic austerity.

> *"It's a political decision who gets these subsidies being made by the Department of Energy and Climate Change and those decisions have a big knock on effect." (E.N2)*

Also, energy security is another driver at the energy policy landscape level.

> *"Once we are becoming less and less dependent on coal and oil, gas is going to be a major, major transition between hydrocarbons and low carbons.[...] We look at the big issues around hydrocarbons the finite resource, where they are coming from, looking at energy independence, certainly within the UK. So not being dependent on importing oil and gas or the petroleum products from Europe, Russia, US wherever they might be. So all of these factors whereas we looking at the finite resource, climate change and everything else, come together actually." (En.L2)*

> *"If we look at the other global factors, the oil price, certainly hasn't been as big a focus until recent months (the interview was on 06/03/2015) but we've understood that there has been an overall decline in oil production and gas production around the world, which means it is a finite resource, then we have to manage carefully, therefore, the fluctuation in price. We have shale oil and shale gas in the US, which is not distorting the market, it is changing in the market in a way that people haven't thought of before. So prices bottom out so we looking at below 50 USD a barrel for price of oil. So that's putting on all sort of pressures on industry, supply chain, consumers, petrol plants, it is not helping jobs in commerce."(P.L5)*

> *"Gas is going to be a really key transition fuel for us, certainly within the UK, probably across Europe [...]. But even the gas industry is evolving with the impact of the oil price. Actually this region, this part of the world has been pretty resilient because we have a gas industry in Norfolk, Suffolk and Essex*

[…]. It is much more resilient to price shocks, the gas price has been rather stable compared to oil price. And we've seen growth." (En.L2)

4.2.2.2 The effect of the macro- economic factors on the development of offshore wind within the electricity system

The UK has been experiencing an economic down turn and has fallen into recession since 2008. The economic crisis has an impact on the availability of public funding for investment in some elements that influence the development of offshore wind energy, such as investment in new technologies, subsidies for CfDs and skills development.

"The country is in a politics finances and the treasurer George Osborne is trying to work out how much the subsidy is good enough to encourage the companies and how much is paying them. He doesn't want to pay them too much, but he wants them to do it." (P.L2)

"I think the global recession is a problem so most countries, the UK for example, is trying very hard to reduce its debts. The subsidies for offshore wind, although they are paid by the consumer, they are viewed by the government as part of the government budget. The government is trying to reduce budgets so there is a huge problem. So from the negative side, every country is trying to reduce its debts and therefore reduce its budget and therefore they are squeezing offshore wind." (SC9)

"There is a reluctance to invest in new technologies from the government level because of austerity. We are all facing cuts to our local services, to our schools, to our NHS and so on and yet we are throwing money at energy projects so I think for the public it is very difficult to get a handle on what it is all about." (CL5)

As explained in section 4.2.1, the offshore wind sector requires specific skills, for the longevity of offshore wind farms, which is estimated to be about 25 years. These skills need to be produced within universities and colleges while the industry shares practices and its needs with academia. The current economic conditions and austerity effect the availability of public funds and subsidies for investment in offshore wind projects, so this effects the continuity of projects. This also effects the universities' training schemes due to uncertain future job markets for specialist skills.

"[…] it can take them up to about five years to get the appropriately qualified people. Well they can't afford to go through that process only to find that there are no jobs available at the end of that process." (P.L3)

"The trouble is now being how big opportunity is, because people are in colleges and everybody if it [the East Anglia ONE] all goes ahead and it is guaranteed to go ahead then you can work out what the sum is for the 1200 turbines, you might need 1000 or so turbine mechanics so you can start organising courses and talking to 16 year olds and 14 year olds about it. In fact, if it is only half that size you only need half. We are at a difficult time when we don't know for some reason." (P.L2)

"The types of work isn't just confined to inside the turbine there is also the external work, the subsea work, the inspection services that are needed that should be carried out on a regular basis throughout the 25 year lifecycle." (C.L4)

The offshore wind sector has the potential to contribute to job creation and thus reduce the unemployment rate. The sector can create direct jobs such as in technical engineering, for technicians, and management positions, as well as indirect jobs such as for transferring vessels. Skilled jobs require a long term training programme which needs to have a clear vision of the potential jobs market, which is missing due to funding constriants, which in turn affects the educational routes for training.

"If offshore wind can demonstrate that it is reducing costs and becoming a much more cost effective option, it's much more likely to retain political support in a climate where the affordability of energy is becoming ever more political." (M.L1)

The offshore wind technology could be a cost effective energy option as it develops and improves over time. It would become a key contributor to achieve the government's ambition to supply affordable and secure low carbon energy.

4.2.2.3 Change in institutions: the effects of cognitive and regulative rules

The UK socio-technical electricity regime includes policy instruments that regulate the existing energy regime to meet climate change and emissions targets. The regulative rules put pressure on the energy regime, and the landscape plays a role in this context through the impact of macro factors. The energy policy landscape influences the regime context, in that, changes are being made to cognitive and regulative rules.

The effects of the energy policy landscape were explained in section 4.2.2.1. In this part, the main focus is on the changes that regulative rules, like the introduction of CfD make on cognitive rules.

The CfD scheme is known as an awards subsidy for renewable energy developers to compete in annual auctions by DECC to win contracts at the best possible price for end users. The CfD forms part of the Government's world leading Electricity Market Reform programme. Offshore wind is a new industry and the technology is in the development phase. The planning for building an offshore wind farm is a long process which requires financial support and policy clarity at each stage. This highlights the importance of subsidy support and the significant role of CfD in promoting offshore wind projects.

> *"Offshore wind is dependent on financial support and therefore the whole industry is looking for predictability from the government not for 1 and 2 years but for 4, 5, 6, 7, 8 years perspective. Because it takes around 1 to 2 years to develop a product and get the manufacturing line and then they need 5 years payback time on what they have invested in to do it and then you are up to 6,7,8 years. So we all need to bring this industry forward and predictability for that period of time." (SC10)*

> *"The problem is that they've got it now and now there are going to be 4 more auctions to 2020, those auctions are going to have a smaller and smaller pot each time of budget. And offshore wind projects aren't your standard 10 MW, 15 MW, they are not small. No one build 3 turbines offshore, no one does 5. It is a 100 turbines it's 50 turbines whatever. So they are going to try and bid in with a big project for a smaller and smaller amount of money each time. And so we've worked out that each year the CfD can support around 800 MW of offshore wind which is around one big farm, for example the East Anglia ONE is around 800 MW. So it's one a year basically." (M.L2)*

"The recent constraints on the Contracts for Difference budgets have meant that the offshore companies cannot look to fund the large parcels of that development they were looking forward to. In fact they may have to reduce their yearly package size by about half which if they do is going to put up the costs of production. So we are not quite sure how we are going to benefit from this […]."(P.L3)

The subsidy available in each auction reduces, which will affect the development of offshore wind projects. In the first auction, the East Anglia ONE offshore wind farm agreed to deliver 714 MW out of its 7.2 GW potential.

"The East Anglia Array has been the largest windfarm here, that's 7.2 GW, that's a massive farm, the overall size is about one and a half times the size of Suffolk and output is about five and half times that of Sizewell B so it is a staggeringly large development. The benefits of that is that the cost benefit ratio and cost per KW is greatly driven down by the size." (P.L3)

The UK electricity system is based on operating large scale electricity generation. DECC estimates that 2.5 GW per annum is needed for offshore wind installation, which requires the continuation of the CfD scheme.

"The DECC scenarios show that 41 GW of installed capacity can be reached by 2030 if annual installation rates remain at about 2.5GW per annum and if 15GW was achieved by the end of 2020. In this scenario, the UK remains the largest European market and will increasingly reap the economic rewards from sustained innovation and growth in services." (D5)

It is understood from the above quote that the UK is ambitious to deliver more large scale generation of offshore installation beyond the 2020 targets. Interviewees also believe that there is potential to grow the offshore wind market and retain leadership in the sector for the UK. There needs to be clarity at the policy level on how further offshore wind development will be supported after 2020 when the CfD scheme is due to end.

"The CfD is still an important factor in the way the sector is at the moment. So the government at the end of the day has money on the table so the industry can bring down the costs as much as it likes but if there isn't enough money on the table going forward in the early 2020's then that is the sort of thing that

investors and developers don't like. So I think in terms of support again if the clarity but also allowing the mechanism of the CfD to bring through that technology and innovation and the competition and skills in the supply chain is really important coming forward." (P.N5)

"In an industry that is subsidised you are always looking at the future so unfortunately everything is build up to 2020 and while that provides short term certainty there is very limited visibility on what the next decade holds for offshore wind and that is not just in the UK that is across Europe as well. So looking at all the other countries between 2020 and 2030, we are still pretty much guessing what the picture will look like for offshore wind and obviously with large companies in the supply chain you need to invest in infrastructure and factories and have that certainty." (P.N5)

Price improvement is one of the key elements that can provide the industry with stability in the market and allow it to mature and compete in the mainstream market. The cost reduction programme has worked for the offshore wind industry since the price of the energy has been reduced significantly to £114/MWh.

"I think we have been quite successful we have already seen over last year, year or two years, the cost of offshore wind come down from a price of £150 or £160/MWh down to £114. We saw the first auction take place last year till end of this year, bring that price down to just under £120/MWh, that is a fantastic result, really shows the success and piece of change […] That's what we need to keep the as a sector and that's what we need to keep delivering. I am confident that we can hit the target and the aim we are set ourselves the government to help £100/MWh for offshore wind by 2020. I think we can get that, and I think we can surpass that and we need to keep pushing beyond that." (F.G5)

The above quote shows a positive response to grid parity of *'£100/MWh by 2020'* from the industry, but visibility of the future market is an essential factor that emerged from the interview data in response to this parity.

"Lack of clarity about the direction of policy affects every generating technology equally and opposite. […] Now government has to intervene, the CfD is a helpful intervention […] CfD's will be available for auction next year, the year after and the year after that […] it is very difficult for the industry to

make any investment. A CfD is great once you get to final investment decision – it gives you a very predictable income stream. But if you have to develop an offshore wind farm might take you 5 – 6 years, 50 million pounds and at the end of that process you get a ticket to the lottery and then if you win the lottery you get a CfD." (SC5)

Furthermore, government objectives and targets regarding the estimated scale of offshore wind that the industry will deliver is also vital.

"An industry like offshore wind needs long term visibility like what government plans in terms of how they would like to resource energy, let's say, in 10-15 years because without having certainty or at least clarity about what is the intention of the government, it is difficult to plan or invest in this very long time frame."(P.N2)

The offshore wind industry is being built upon the reorientation of the existing energy industry who have a stable position in the energy market, and stable assets and resources. The offshore wind industry does have the potential to become subsidy free, subject to the clarity of the future market, government ambitions and objectives.

"Let me be clear, absolutely clear, my view is we need to get that point where we do not rely on subsidies, we need to get this industry to be subsidy free that has to be our aim, that has to be our ambition and we have to do it as soon as possible. Because that's the only way we have got it to a longer future from what we do to and what we want to deliver and what we want to create." (F.G5)

In summary, it was evident that in the electricity system, the energy industry and incumbent firms are within the processes of transition and are adopting with the offshore wind system as a new and clean technological system. The analysis has explored the development of offshore wind within the three distinct processes and evaluated the interactions of the three MLP levels (niche, regime and landscape). The analysis of the interaction between the three levels shows the possibility of the wider changes and explains how the institutions can be supported, shaped and changed to enable the further integration of the offshore wind system into the electricity system.

4.2.3 Opportunities

Economic conditions impact government funding; however, the funding constraints can bring opportunities for the offshore wind sector to attract more of the available funds due to the excellent natural resources available, particularly off the East coast of the UK. The government has put emphasis on promoting low carbon technologies to reduce the unemployment rate and boost the economic conditions the offshore wind sector to deliver these ambitions for climate change and carbon emission reductions (D1). The UK has the world's largest offshore wind market, and retaining this leadership is the focus of policy makers with respect to the development of offshore wind.

> *"The rest of the world is now rapidly developing, its plans for offshore and its infrastructure and UK is still the world leader at the moment for having more capacity installed than the rest of the world combined and that would continue for some time." (En.L2)*

It was also argued by participants that the development of offshore wind energy can contribute to government aims in terms of job creation and economic growth as well as promoting the development of low carbon technology.

4.2.3.1. International joint venture

Being the market leadership enables the UK to attract outsider firms into offshore wind market. Joint ventures with international firms increase competition in the market and also increase the investment and capital flow into the UK offshore wind market.

> *"A joint venture between EEW Special Pipe Construction GmbH and Bladt Industries A/S, come into produce foundations. These are multi million pound deals that are starting to build an infrastructure that will create opportunity for UK suppliers." (En.N4)*

> *"If you look at a broader level across Europe you are actually seeing the four or five joint venture companies and seeing what is left in the market, the amount of competition is increasing. And with the lower expectation in terms of capacity it was just inevitable that we were going to lose supply to the market. So I will say that it is not a negative thing that we are losing suppliers and we are not getting new entrants into the turbine side because I think it is really good for*

competition that the companies are forming joint ventures and bringing a much more competitive commercial offering to the market." (P.N5)

"There are three or four projects coming up before 2020 including East Anglia that require jackets and there aren't the suppliers in the supply chain. There isn't a large enough supplier that can deliver all of that, that can cater for all that demand so it is very likely that in the foundation side we might see something similar in the consolidation of companies forming joint ventures in order to provide their supply." (P.N5)

Joint ventures form commercial operations within the market which increases the level of competition between suppliers. Furthermore, forming joint ventures fills gaps in capability. For example, for the East Anglia ONE offshore wind development, joint ventures with other suppliers for the foundations helps to overcome local skills and reduce shortages and accelerates the timing of the operation. Joint ventures can be formed for capital investment as well, such as financial investments in operation, manufacturing, infrastructure and so on, which are explained in the next sections.

4.2.3.2. Inward investment

Despite the public funding constraints, offshore wind has the potential to attract inward investment from outside the UK into its energy market.

"Obviously getting people to invest in offshore wind is really important. The developers don't have enough money, they haven't got enough funds on their balance sheets to be able to finance these wind farms by themselves. [...] a two billion euros wind farm is too expensive for most developers. So we need to attract investment into our offshore wind farms." (SC9)

"UK investment in offshore wind is increasing economic opportunities for UK businesses (...). Recent supply chain analysis shows that 43% of the lifetime cost of a UK wind farm is spent in the UK; this translates into real jobs. Manufacturing related to the turbines themselves remains largely at this point in Germany and Denmark, but the resources required to project manage and install projects has grown extensively in the UK."(D7)

> *"We were quite optimistic about the great opportunity for the sector, the opportunity to get manufacturers involved in that. What we have seen over the [government funded plan] is that some of the infrastructure is starting to be placed in the UK. So we have seen a big investment [turbine manufacturer] in Hull to build a turbine factory, we have seen [developer] increase their facility in the Isle of Wight to make blades and Offshore Wind Structures in Britain (OSB) […] and we saw AB ports being developed and these are multi million pound deals that are starting to build an infrastructure that will create opportunity for UK suppliers." (En.N4)*

The aim of the UK government is *"to ensure the UK can capture maximum economic benefit both through investments bringing growth and jobs to the UK and through further cost reduction in offshore wind." (D7).*

4.2.3.3. More technological innovation: Repowering

There have been concerns about the decommissioning of offshore wind farms when their economic life comes to an end in the 2020s. Innovation can create more adaptable and cost effective solutions to address the decommissioning concerns. It has been suggested that the old and low performance wind turbines with lower output can be repowered with higher technology turbines.

> *"There are many upsides to repowering offshore wind. Alongside providing a long term source of low carbon energy there is the scope for ongoing cost reductions and also a significant industrial opportunity." (D4)*

Repowering and re-using the wind farms enable the offshore wind industry to reduce the cost of energy through replacement of the old technology with new higher output technology, which is performing in lower cost. Through the repowering process, there are also opportunities to create jobs which boost local economic growth.

> *"Each new or repowered offshore windfarm offers guaranteed, stable jobs for another 25 years for local coastal communities." (D4)*

In addition to that, re-using the foundation prevents marine wildlife from being disturbed. Wildlife under the sea has started to build habitats within and between the offshore foundations.

"I think it [marine life under the sea] has been a change and a growth in different ways of livings offshore and I think, as far as I know, the majority of habitats have settled down and in some ways have got some benefit from it. Once they have been there for a while, they are actually creating false reefs offshore. And also because it is not that convenient for vessels to fish in between them [offshore wind turbines], the fish feel a bit safe. So we are creating new habitats for the growth of fish and marine animals offshore and that seems to be quite a beneficial knock on towards things." (E.L3)

4.2.3.4. Effect on local economic growth

Offshore wind development creates direct and indirect jobs, which is one of the government's aims in terms of reducing the rate of unemployment.

"I suppose to the region is about attracting inward investment to create jobs, so getting the large Tier 1 companies to base themselves here and get SMEs to provide goods and services to them in our ports." (P.L2)

"Particularly growth offshore is estimated to create 13,500 jobs and that's the first time really that these two coastal towns have had that opportunity to draw in that amount of jobs as well as all the investment that goes with it. So for us, this is absolutely key to our future growth of the New Anglia area."(P.L3)

The development of offshore wind has also created indirect jobs that boost the local economy. The increase in the number of offshore wind farms off the coast of Great Yarmouth and Lowestoft provides opportunities for boats owners who are experiencing decline in fishing and boating activities.

"I think there was concern in the fishing industry about what would happen to them, if there was a decline in fish, the people who were operating the boats, the fishing vessels. But what we have found is that a high percentage of the skippers and crew that used to run the small vessels particularly, now operate and run the fast ships that serve the offshore industry and they are earning a lot more money than when they were bringing in fish with the sort of declining industry." (E.L3)

"That would bring huge amounts of jobs into our ports, huge amounts of jobs to coasts and communities, which have been radically deprived over recent

decades with decline in the industries like fishing and other maritime industries. So hopefully that combined with tourism will be significant, contribute for regeneration in our coast communities and port related sectors. So, it is huge opportunities which we have to grasp but it is not without its challenges." (C.L1)

Apart from those skilled jobs that the offshore wind sector potentially creates, there are a high percentage of indirect jobs that are linked to the growth of offshore wind. This provides opportunities for the local economy in terms of creating jobs and increasing the flow of capital.

"With any large construction project that you go through the benefits that you receive are not just about the actual piece of construction that you have, it's about the overall wider effect it has on communities. […] the amount of jobs in the catering side and the hotel side and the housing side […] And if we think about the total number of jobs that this could create offshore, in terms of those working onshore and offshore, quite a percentage of those are in the indirect category. So people have even worked out the number of barbers you will need to cut the people's hair who work offshore." (P.L3)

"Once they [offshore engineers] start living in the area they generate their own income levels but they then spend that income in the local community. And it's that local community, that spin round of money in the local community is worth 4 maybe 5 times as much as their own income levels. And that growth, if you add that up by the number of people and the average value of work offshore, I think typically here (Lowestoft) average adult wage is about £19,000, offshore it is £60,000. Now that is a significant difference in your disposable income that you can use and the effect of that disposable income in the community. I don't think the general public are aware of how high the extent and that level of knock on effect is." (P.L3)

In line with the above quote, statistics suggest that *"60-70% of the workforce"* (D7) employed for the latest offshore wind projects have been based in the UK. Due to the embeddedness of the offshore wind projects to locations and the development of new wind farms like East Anglia ONE, it is predicted that offshore wind development will bring considerable benefit to the East Anglian economy by creating both direct and indirect jobs.

4.2.4. Section summary

Data shows that technological innovation, the development of high performance wind turbines and the development of the supply chain will all help to reduce the costs of offshore wind. In parallel with this, section 4.1 showed that policy certainty and a long term view of the market also influence the development, in terms of investors' confidence in supporting new and ongoing offshore wind projects. The supply chain needs to be mature, stable and industrialised, to be able to reduce costs, and it needs to improve its capability and performance, as identified through the interviews for this research. Participants also suggested that transferring skills and technology from incumbent firms in the offshore oil and gas and other related sectors will help the offshore wind supply chain to improve its performance. Joint ventures and projects and continuous collaboration with energy industry and learning processes will also help to further develop and mature the sector.

From the regime actors' point of view, there is potential for established energy firms to increase their involvement in renewable projects. Incumbent firms not only have long term experience in the electricity market, but they also have resources and assets which can be reoriented and reused. This transformation will have two results: firstly, it will accelerate the development of renewables (offshore wind in the UK is currently more feasible than other renewables), and secondly, it will provide opportunities for the supply chain for further collaboration and joint projects with the energy firms. This is a win-win situation as it saves time for energy firm and developers as the project can be brought under one umbrella, and the supply chain can improve performance, efficiency and standardisation and reduce costs due to the continuity of doing projects.

High performance wind turbines will enable the development of wind farms into farther and deeper water, where the wind speed is greater and electricity production will be higher. Maintenance management will be increasingly important to reduce costs and will require extra funding due to the increased distance from the shore. New methods will be required to reduce maintenance costs, such as improved and facilitate crew transfer to the wind farms.

Overall, it is predicted that the growth of the offshore wind sector will have positive effects on the local economy and accordingly on the national economy due to direct and indirect job creation and the knock on effect that these employees have on the region.

4.3. Research Question 3: the role of social actors in the processes of socio-technical transition

In section 4.1, the effects of multiple factors that were characterised and interpreted by multiple social actors were evaluated. Section 4.2, used these insights to analyse the effects of these factors on developments at the three analytical levels in the processes of transition. Section 4.2 also analysed the interaction between the three analytical levels (niche, regime and landscape) by including key influential elements in the process of transition to see where the challenges and opportunities are for the development of offshore wind energy. Both of these analyses together illustrated the actors' perspectives towards the development of offshore wind energy. Based on these insights the current section focuses on the role that key actors play to meet the unified aim which is to transition to a sustainable electricity system.

The development of a technological system requires increasing the degree of stability and reducing the cost of the technology. It is essential for actors from the energy firms, the supply chain, local and national policy organisations to share their views and interpretations, and develop and shape a shared belief system, in order to reach agreement to the best possible way for offshore wind development.. Establishing a network enables social actors to share their views about the opportunities and barriers to achieve a sustainability transition within the electricity system.

To increase the level of stabilisation of a technological system, the SCOT theory suggests that social groups *'redefine'* the problem (Bijker et al., 1987), which can be facilitated through networking between the different groups. This highlights the role of social actors in the processes of transition. Therefore, the current section aims to answer the third research question: 'what is the role of social actors in the processes of socio-technical transitions towards a sustainable low carbon electricity system?' This section explores the importance of networking between relevant social actors which was highlighted by a majority of participants.

4.3.1. The role of networking

The offshore wind sector includes multiple actors from a wide range of disciplines with diverse perspectives. These groups consist of manufacturers, suppliers, developers, operators, managing sites, regulators, policy organisations, investors, and energy businesses. In order for these broad groups of actors to reach a shared vision, an increase level of collaboration through the network is vital. Networking is an effective method for sharing beliefs and views which was highlighted by participants.

> *"There will be the supply chain days when the big developers will come and say: 'can somebody talks to me about all those things? We would like to see companies about these things and can you send us what we can do about these things'. So they'll start to engage with local companies." (P.L2)*

> *"I have worked in local government here for 41 years now and I think this is the first time I have ever seen the amount of cross partnership working that has gone on actually to maximise the benefits to the UK for something like this, and it is nice to be involved in something like that, it really is." (P.L3)*

The above quotes show that networking provides opportunities for both the supply chain and developers to increase partnerships through collaborations. It also indicates the importance of networking for further collaboration between actors. Although, collaboration minimises the gap between the development and supply side, participant C.L4 believes that it is difficult to identify local supply chain organisations within the sector to collaborate with:

> *"The problem is that suppliers in the region struggle to understand who is that they should go and speak to and who, and what role within that organisation they should also identify and contact. […] A company like ours has a very strong track record of installing submarine cables and on much larger projects than most of the offshore wind farms require and yet those developers still struggle to recognise us as a qualified and competent supplier." (C.L4)*

The data shows that, collaboration between actors (specifically local supply chains and developers) needs to develop further to create better outcomes.

> *"It is absolutely key that we [local authority] work with the licence holders offshore. We've worked with them to understand what their programme of development might be and all the different phases involved there." (P.L3)*

"I think the important thing to bring out is that there is a complete link between central government, New Anglia LEP and both the counties and the district councils in the New Anglia area. We are all working together and we realise how significant this is for the area, and that has driven forward relationships which weren't there before this type of opportunity came forward." (P.L3)

"They [outsider offshore developers] are going to have to work hard to get the local content. And I suppose that it is the good thing for us [local authority] because it means they want to talk to us […] about what companies we've got here what services they could provide. We tried to make it easy for them. So we've listed the activities they need to build a wind farm […] in the local area in the matrix that is needed for a wind farm when we give that to that people they say: 'I can't believe you've got this, this is so useful'. So that is another way we promote the local companies by bringing them to the attention of the people who need to deliver on this local content." (P.L2)

Data shows that the role of local authority is vital to increase the level of collaboration. Therefore, the network is essential for the broad social groups of actors in the offshore wind sector. Through the networking, the social actors maximise the level of collaborations by considering shared perspectives. Moreover, the networking links social groups. This link is important for the offshore wind sector, especially the link with the policy and regulatory bodies, as policy is a major driver for the development of offshore wind and plays a significant role in the main aspects of development such as subsidy and investment.

"We have chosen to create an energy zone ourselves, because there are a number of projects in energy available. There will be a new nuclear power station, an existing oil and gas field out here […] and obviously there are some offshore wind activity. So we see ourselves as being all energy and having strengths because we have got three sectors of energy production." (P.L2)

Creating the Energy Zone is a practical example of networking. The Energy Zone incorporates the local supply chain across the whole energy sector.

"I feel that at the moment the supply chain has very little influence apart from voting and being more vocal, but the developers are probably the people that could do it but they are not necessarily wanting to do it because they have other areas of interest that conflict with offshore wind." (C.L4)

In addition, through the networking, shared visions between social groups develop. The above quote illustrates a lack of shared vision between the social groups. However, through increased networking between social actors, gradually a shared belief system will be shaped, helped by a clarification of objectives, demand and targets, and then future achievement of those targets.

4.3.2. Impact of coalition and lobbying

Working closely with the supply chain enables policy making bodies to understand the opportunities and risks. This highlights the importance of networking between the supply chain and public organisations.

> *"I think DECC is starting to confirm that with communications last week (interview date 28/07/15) about the subsidy budgets and indicating which renewables they will continue to support. So offshore wind on top of all the renewables, seems to be the one that is obviously coming through." (En.N4)*

Policy instruments that support offshore wind development can be changed by lobbying of the government from incumbent energy firms, like oil and gas, who have established position in the electricity market.

> *"I think that there was probably a lot of discussion between the applicants and the government to try and make the numbers all fit so the government was probably going back and saying 'we really need to do this' and then they had to go back and see if they could make that happen. But strategically given that we have just had a major debate about Scotland leaving the UK, there was one Scottish project and one English project and the Scottish project was awarded in its entirety as it was originally designed. The English project was scaled down to fit and I would imagine there was some negotiation over getting the price right, I may be wrong, but it does seem a surprisingly good outcome not long after the Scottish debate and prior to an election. So I think there was a large degree of political manoeuvring to make everyone happy and make them feel as though there was some successful award here. So, yes, that was interesting anyway, that's just a personal view." (S.C4)*

4.3.3. Political will and cycle

As political parties change in a five year cycle in the UK, depending on which party is in power, support can vary towards offshore wind energy. The political cycle can enable innovation, but it can also destabilise the confidence of investors who are funding innovation.

> *"We have a general election in May (May 2015), so timetables may change, policies may change, and I don't think any new government or even the same government being retained, would play with or amend energy policy supremacy." (En.L2)*

> *"There is a reluctance to invest in new technologies from the government level because of austerity." (CL5)*

> *"I think the one caution is that it is expensive and so either the public will have to bear those costs or be told by the politicians, look, you are going to have to pay them. Which they are not at the moment, the politicians have kind of, well: Labour are saying we want to cut people's bills, well, why would you do that while the costs are increasing; others are saying we want a green agenda; and others are saying we don't want a green agenda. But then none of them talk about the cost. So the cost is going to have to be explained to consumers and once that is explained then I think people can get behind offshore wind more." (M.L2)*

Political views have changed over time and depend on who is in power and the economic situation. In recent years, there has been a period of economic austerity. This has affected the sustainability goals, the development of renewables and especially offshore wind.

> *"It [offshore wind] is expensive and it is dependent on whether the politicians hold their commitment to KYOTO and all those things because can we afford to do it […] So renewable energy targets depends really on whether the government can afford to maintain the subsidies to achieve them and/ or something doesn't come from the side and change the game." (P.L2)*

"We delivered our commitment because we shifted from coal and oil fire power generation to gas fire power generation as well as developing our renewables capacity. Because gas as a hydrocarbon has a much lower carbon contents than oil or coal. So, it seems to be a bridge between hydrocarbon and a low carbon economy. So it is kind of a medium carbon economy. But gas is going to be a really key transition fuel for us, certainly within the UK, probably across Europe." (P.L5)

This quote shows that the EU commitment can also be redefined due to economic austerity which changes the view on investment in relatively expensive new renewable technologies, specifically offshore wind, to instead rely on the gas industry which is an established low carbon industry. The next section considers changes in visions and cognition.

4.3.4 Changing cognitions

As sustainability transition of the UK electricity system needs to be understood by social actors. Each of the social groups that are involved in specific and different aspects of meeting the targets need to share their views, best practices and experience through networking and communication. This leads to a change in cognition and visions based on how social actors define demands and redefine issues within their belief system.

"I am not a big fan of CfDs and I think they will actually be altering legislation for the next few years to try and make CfDs work because I don't think it will work successfully in its current format. So I think there is going to be a number of legal challenges and changes over the next few years to make it fit." (C.L4)

As data illustrated the aims of promoting specifically offshore wind in the UK is to create jobs and reduce the unemployment rate, to drive down the cost of energy, and to meet emissions and climate change targets. Those targets are achievable through the industry and performance improvement; however, it is important for the sector to have clarity on the future market size.

"It is uncertain whether the current market conditions will support further long term investment in technology development and supply chain industrialisation. There is limited capacity within the current CfD auction process and little clarity of the market beyond." (D2)

> *"An industry like offshore wind needs long term visibility like what government plans in terms of how they would like to resource energy, let's say, in 10-15 years because without having certainty or at least clarity about what is the intention of the government, it is difficult to plan or the investments in this very long time frame." (P.N2)*

The data suggest that 'clarity' should be the central focus as opposed to certainty when the objectives and targets are defined through the network and to build an agreement between actors about what is achievable. It also emphasises clarity on the future energy mix, which together with technology improvement, reduces the cost of energy while minimising the political risks. So clarity allows the supply chain to invest in UK jobs and brings the focus of social actors together on delivering the targets efficiently.

4.3.5 Section summary

In summary, the offshore wind sector includes a diverse set of social groups, which may have different perspectives and interpretations about the future of offshore wind energy. This has been done in section 4.1 where *'relevant actors'* identified a wide set of factors that affect the development of offshore wind system. In order to meet the aim of sustainability transition, the social actors need to share certain views about the development of the sector and the overall objectives and targets that will guide it. It was evident that the social groups can use networking to align their views, which leads to changes in the cognitive rules, which affect the development of the offshore wind sector.

This network is shaped through learning processes which link the supply chain as niche actors with the energy firms as regime actors, but also includes a wider set of actors to create a shared belief system within the sector. In terms of the common issue 'uncertainty' emerged by all participants through the fieldwork. It has been suggested that to redefine the issue that causes uncertainty within the network, so 'clarity' in energy policy and in the future of the development of the sector was recommended. This clarity creates the confidence to invest in the sector and will enable stabilisation and industrialisation, as well as reducing costs and improving technology, skills, efficiency and performance within the offshore wind sector to enable it to compete in the mainstream electricity market.

Chapter 5: Discussion

5.0 Introduction

The main purpose of this research is to explore the role of offshore wind system in the processes of socio-technical transition towards a more sustainable (low carbon) electricity system. In doing so, in the Chapter 4 the effects of multiple factors on the socio-technical transition to a low carbon electricity system identified and analysed. It is important to analyse the interactions between elements of the socio-technical system: social groups of actors, technology and institutions to understand the possible transition pathways. So, the aim is to uncover the effects of different interaction mechanisms which occur during the processes of transition on the development of the offshore wind system within the UK electricity system. The introductory chapter discussed the main debates surrounding the existing electricity system. It identified different factors that influence the energy policy landscape and the development of the offshore wind system within the existing system. Chapter 2 provided theoretical insights and explanations regarding change in socio-technical systems (systemic change) and sustainability transition in primary systems and considered gaps in the literature. This contributed to establishing a theoretical link between Geels' (2002) multi-level perspective (MLP) model of transition and Pinch and Bijker's (1987) ontology of social construction of technological system.

By using these approaches, a useful platform of theories and concepts can be applied to analyse the interaction between technology development, institutions and social actors. It is argued that the MLP enables different types of interactions between the niche, regime and landscape levels to be explained. For example, the MLP framework considers practices at the micro level and reflects on how this is institutionally structured, embedded and shaped by the regime and landscape levels. The constructivist approach proposes a tool to analyse the interplay between technological systems and social actors. Because technology is shaped or developed through the interactions between actors and institutions and it is also embedded in a context that is socially constructed, it is important to understand how social actors characterise and interpret changes in new technological systems. Therefore, as was discussed in Chapter 3, an inductive method is an appropriate approach to inform the dynamics of interaction between actors, institutions and technologies in socio-technical transition processes.

In the findings chapter a number of inductive themes, which emerged from the semi-structured interviews, were identified to analyse the processes of transition through interaction mechanisms between social groups of influential actors, technology (offshore wind) development and institutions within the electricity system. Also, the effects of multiple factors on the processes of transition were illustrated. This research analyses the specific technical and institutional (non-technical) characteristics of offshore wind as a low carbon technological system in the processes of transition. The data reveal new forms of interaction between social actors, institutions and technology in the UK transition pathway to a low carbon energy system with regard to offshore wind development.

Therefore, these phases are collectively linked to address the three interrelated research questions:

(1) How do non- technical and technical factors affect the development of the offshore wind system within the UK energy regime?
(2) How are the transition processes within the energy regime affected by offshore wind development? What are the effects of the interaction between levels in the socio-technical transition processes on the sustainability transition?
(3) What is the role of social actors in the processes of socio-technical transition towards a sustainable low carbon electricity system?

It will then be possible to answer the overarching research question:

'What are the effects of the socio-technical transition processes on the development of the offshore wind system to transform the electricity system towards a more sustainable configuration?'

The aim is to investigate the possible transition pathways that occur during decarbonisation of the current electricity system.

In turn, the discussion chapter examines the empirical data and focuses on how theories apply to the research findings. The discussion chapter demonstrates how this study informs the existing literature. Therefore, the purpose of this chapter is to induce the context specific knowledge, which was developed in the empirical chapter (Chapter 4) to reflect on how this knowledge informs theoretical explanations regarding the socio-technical transition of the electricity system by the development of offshore wind system. It is proposed in the empirical chapter that the offshore wind system will become a progressively important part of the UK energy system in the future.

However, the development of the offshore wind system within the existing electricity system is a long term process that has co-evolved and the interdependence of technology and institutions has shaped this evolution through a series of interaction mechanisms. This chapter aims to explain the interaction mechanisms between elements and within the socio-technical system which illuminates the effects of transition processes to inform the literature. Also, it aims to illustrate how the analytical framework that was proposed in the literature review in Chapter 2 and conceptualised in Chapter 4 has uncovered novel interactions between the technological development (which is socially shaped by human actions) and institutions (which are in turn socially constructed through human actions).

To achieve these aims, this chapter begins by discussing the outcomes of the findings chapter through the lens of the existing literature on technological development and interactions of this development with the 'multilevel actors' involved. Then the discussion expands further to include the interactions of institutions and technological developments to illustrate how offshore wind as a socio-technical system is empowered and gains legitimacy. In the final section of this chapter possible transition pathways within the electricity system are discussed.

5.1 Niche development under social construction processes

This study attempts to show the importance of interactions between social actors, technological development and institutions in the electricity system in the processes of transition. Taking a constructivist approach, technological change is a process which involves *'conflicts'* between multiple social groups of actors (Williams and Edge, 1996) in how they interpret the technology (technological change) and how the technology is designed and deployed. The deployment of technology is understood in how social actors create *'shared interpretations'* of the technology which is embedded in its social context (Berger and Luckmann, 1966). Technological change as a contested process emphasises the importance of *'interpretive flexibility'* between social groups of actors (Williams and Edge, 1996).

The findings showed that for the transition within the electricity system, the processes for offshore wind development, will reach the point of *'closure'* when 'multilevel' actors in this study which refers to social groups of actors from the niche and regime levels, achieve a shared interpretation or agreement of 'clarity' in terms of *'scope'* and *'scale'* (Raven et al., 2012) of technology configuration.

However, the extant literature emphasises the temporary nature of closure due to the emergence of new sorts of interpretive flexibility (Murphy, 2007, P.9). Since transition is an ongoing process, the findings suggest that closure becomes undone at some point and new forms of conflicts and interpretive flexibility occur in the form of 'uncertainty' within the system due to a range of changes in technological developments and institutions such as policy.

New forms of interpretive flexibility occur when social groups of actors seek to understand and adapt future configurations of technology development based on their interests. The SCOT theory suggests that social actors interpret different meanings of a new technology (Bijker, 1997), whilst this study argues that multilevel social actors attach different interpretations to the implementation of technological change. The empirical analysis depicts within the existing electricity system that the development of the offshore wind system requires a range of changes in institutions relating to the scale of technological development in connection with 'market visibility' and 'policy certainty'. This leads to further interpretive flexibility between policy makers and the industry (including incumbent energy firms, developers and standardised supply chain) and investors.

The uncertainty of future policy supports and market visibility affect the 'industry confidence' preventing further investment in offshore wind innovations. The empirical data demonstrated that the government forces the offshore wind industry to drive down the cost and to compete with established gas and nuclear as two low carbon sources of energy. Also, empirical data based on Amber Rudd's Energy Minister statement, from the Department for Energy and Climate Change, found that future subsidies will be guaranteed on three more CfD awards, if these conditions are met by the industry. These findings illustrate that within a system, different views of multilevel actors can affect the development of a particular technology.

These outcomes are in line with Geels' (2010) findings where he concluded that different views emerge due to the absence of *'shared visions'* and interpretive flexibility processes which occur during the development of a less established technology configuration.

These different visions occur as a result of uncertainty in the long term market visibility and uncertainty of government policy support for the development of the offshore wind system. These uncertainties mean that the industry is less confident to invest in R&D and infrastructure related to offshore wind technology development. This also affects the incumbent firms' integration into offshore wind technology while southern North Sea gas is a guaranteed and secured national source of low carbon energy in terms of subsidy and investment. These examples of divergent visions that emerged from the findings illustrate how multiple actors seek to interpret and to make sense of the future development of the offshore wind system. As a case in point, the industry participants proposed 'clarity' over cost reduction which requires greater 'clarity' that future subsidy is going to be made available for CfD beyond 2020 and 'clarity' over the size of the market and the scale of projects. Overall, these multi visions from multiple actors can also affect the processes of transition towards sustainability.

In this regard, visions and scenarios for the future development of a new socio-technical system are based in *'negotiation'* processes which embody the interests of the social actors who advocate them (Geels, 2010 and Smith, 2005). Based on these arguments, a transition's aim is met at a closure point between multilevel actors. The evidence from the empirical data shows that clarity (shared goal) of future market size and project scale is necessary for the development of the offshore wind system. This agreement (closure) can be reached through interactive processes such as 'collaboration' between supply chain and the incumbent firms and negotiation between the industry and policy makers. Similarly, Stirling (2007) noted that sustainability transition are deliberative learning processes among social actors (Geels, 2010).

While a constructive approach emphasises cognitive learning through interaction processes such as interpretations, sense making and negotiations, aimed at the creation of shared interpretations by actors (Berger and Luckman, 1966), evolutionary theory views learning processes as behavioural processes involving learning by doing through performance improvements (Geels, 2010, Gavetti and Levinthal, 2000).

Although SCOT, as an actor-centric theory, explains the interactions between social actors and technology, it is unable to analyse the effects of institutions in a long process of transition. Therefore, in the next section, the discussion about learning processes takes advantage of both views.

5.2. Learning processes

The evidence supports the notion that learning processes, as one of the major elements of transition theory and the MLP, are essential for driving internal niche momentum for the stabilisation of new technologies (Geels and Schot, 2007, Verbong and Geels, 2007, Kern, 2012). Given the focus on the transition processes, this argument can be broadened to include learning as a social interactive mechanism to support niche experiments from the existing regime actors. The findings revealed that offshore wind technology has been developed through the modification of onshore wind technology and by transferring mutual technology from the offshore oil and gas sectors. This finding supports the argument that niche-regime interactions form the support from regime actors for stabilisation of the offshore wind technology. Therefore, support from regime actors is an integral part of the learning processes.

This research revealed social learning as interactive processes between multilevel actors can solve the problems of sustainability transitions when hindered by interpretive flexibility. These problems can be met over the processes of incremental innovation within the existing regime, single loop learning, through investments on innovation experiments and reorientation. Also, technological change requires double loop learning within the existing system over strategic reorientation, changing cognition and existing beliefs. Therefore, sustainability transitions can be facilitated when multilevel actors reach *'socio-cognitive'* agreement (closure) about the best possible approach through interactive mechanisms such as learning processes (Geels, 2010, Bos and Grin, 2008, Rotmans et al., 2001, Stirling, 2007).

Learning processes include the development of lessons such as specific skills and knowledge of doing a specific design that accumulates and improves through practices and experience in supporting niche experiments (Smith and Raven, 2012, Kern, 2012, Geels and Schot, 2007, Shackley and Green, 2007). Following evolutionary economics, Nelson, Winter and Dosi show that technological innovation is a basis for change in institutions (Dosi, 1982, Dosi and Nelson, 1994, Nelson and Winter, 1982) which is vital for learning processes in terms of performance improvements (Geels and Schot, 2007, Geels, 2010, Kern, 2012). The findings from this research showed that the supply chain is playing a central role in the development of offshore wind. As a case in point, the more standardised supply chain can secure the cost of the technology which results in further development.

The empirical findings showed that learning in practices is used for technological experiments to improve capability (standardisation) of the offshore wind supply chain through innovation towards stability (industrialisation). Moreover, technological learning practices are used to improve the technology for products designed for offshore wind. An example is the replacement of the old generation of wind turbines which were developed based upon marinised onshore wind technology by using higher performance turbines with bigger blades and a more efficient swept area of blades, which requires a smaller number to be installed, but achieves a greater output capacity 7 or 8 MW. This is because incremental innovation affects the improvements in the existing technological capacity as well as the cognitive abilities, such as the skills and experience acquired by the continuity of executing projects in the offshore wind sector.

The development of skills, knowledge and resources are essential for the technological change (Unruh, 2000) in terms of the price of production and the transfer of resources from low-return to high-return employments (Dosi et al., 1988). It was found from the empirical data that because approximately 80% of the skills are common to all of the primary energy production sectors, the supply chain has taken advantage of transferring skills associate with reskilling and retraining programmes to improve their capability and cognitive abilities for delivering projects. This strategy worked in the early stages of the development of offshore wind technology. This finding concurs with that from Rosenberg (1994), where he argued that technological change reflects the current stock of knowledge, which is shaped and influenced by an accumulation of past knowledge.

Moreover, studies showed that new technologies are required to improve price and performance in order to compete in the mainstream market (Verbong and Geels, 2007, Geels and Schot, 2007, Geels, 2010, Kern, 2012). These arguments are also supported by evidence from Unruh (2000) and can be integrated with the evidence from the research findings to show the importance of skills, knowledge and resources in the development and improvement of the offshore wind technology.

The empirical data showed that developing partnerships between the energy industry and educational organisations, such as for apprenticeships and graduate schemes, to provide training in the specific skills needed for the offshore wind industry is key to address the specific skills problem. Unruh (2000) also finds that industries and firms, funding bodies and educational organisations can increase performance within the sector by creating standardisation, by developing and supporting new technologies, and by understanding social demands.

The empirical data revealed that the capacity of the supply chain improves with the continuity of delivering projects. It was evident from the empirical findings that the offshore wind supply chain with the experience of installation (continuity) is more practicable to be able to reduce the costs of operation and to increase power generation. Similarly, Arrow (1971) showed that the experience that accumulated through practices such as development and investment processes can increase production and decrease labour costs.

The empirical evidence from this research supports the importance of learning within practices and innovation, which reduces the costs of maintenance by for example building floating hotels for the offshore crew and using heli-workboats to transfer engineers and technicians to the field. These innovations help to reduce travel time to the field, increase efficiency and increase production. The findings also showed that learning processes enable technologies to be improved through incremental innovation processes based on using complementary technologies from other offshore technologies (Bohnsack et al., 2014, Geels, 2011, Rothaermel, 2001). Also, in line with Geels' (2011) and Unruh's (2000) findings, the research revealed that repowering the offshore field is a method that uses past technology and knowledge to increase the technology performance, which results in an increase of capacity within the supply chain enabling a reduction in overall costs and helps to achieve economies of scale.

This study reveals that the supply chain is shaped by institutions and practices, and has developed on historical knowledge, which has been developed and improved. It was found from the empirical data that the supply chain, whether confronting a new technology or an incremental technological change, needs to develop capacity, to improve capability, and to increase learning within the existing energy system. It needs to provide resources and skills for both the development of new technology and the improvement of existing technology, where there is potential path dependency for technological improvements. This supports the argument that capability and performance improvement and learning processes are integral parts of the standardisation of the supply chain. These arguments are supported by evidence from Hogget (2014) to show the importance of the improvement in supply chain's performance in order to increase competition and to reduce costs.

As it was discussed, learning processes, incremental technological change (through complementary technologies) and skills are rooted in existing knowledge and resources which can be used to create new knowledge and skills for sustainability transitions. These processes create path dependency which leads to additional interpretive flexibility from incumbent firms in the selection of new technological innovations (niches). This may reflect that the incumbent firms select those niche experiments that are feasible in terms of returns on investment and economies of scale and that fit with their complementary technologies and resources. Incumbents form a type of *'complementary adjustment'* to create new knowledge. Therefore, the next section discusses the key factors that are important to empower those niche selections.

5.3 Niche empowerment

This study found that offshore wind energy has been positioned as a feasible source of energy for the specific geographical location of the North Sea and contributes to the UK's sustainability goals (Kern et al., 2015). The empirical data evidenced that the East Anglian location, bordering the Southern North Sea, is well-positioned for the deployment of offshore wind power (69% of the UK total capacity) in terms of natural resources (such as shallow water and high wind speed) and proximity to the shore as well as to the offshore wind market where Germany and the Netherlands are big competitors. These natural resources provide a 'geographic selection' environment for the development of offshore wind energy in this particular area.

However, based on empirical findings, the development of offshore wind in this area requires some infrastructure development such as providing extended landing areas for mantling blades, and port facilities and services for handling offshore installations. It was found in the literature that this infrastructure requires *'geographic protection'* due to the uneven and high costs needed to develop it (Smith and Raven, 2012).

The findings in this study showed that the availability of port facilities and services is important for developers (regime actors) in terms of being suitable for installation, and operation and maintenance of offshore wind projects. Although infrastructure development (port facilities and services) is not directly linked to the development of offshore wind as a technological innovation, it is possible to add a positive influence on the local economy beyond servicing offshore wind developments.

The current UK electricity system is widely locked into large scale of high carbon configuration that is dominated by six large incumbent firms (Geels et al., 2016, Lockwood, 2016, Foxon et al., 2010, Shackley and Green, 2007). This means that the energy industry falls into technology lock-in and large sunk investments, which tends to prevent investment in new infrastructure related to technological change due to high capital costs, long term return (Scrase and MacKerron, 2009) and uncertainty over the future market growth and energy policy. Lock-in and path dependency mechanisms support the argument that the incumbent firms select *'particular innovations'* (Shove and Walker, 2010) relating to a new technology that allow them to maintain their resources and assets through slow incremental change. It was also found from the literature that advocates for the niche provide *'shielding'* by mobilising some of these resources to enable some degree of development for technological innovations (Raven et al., 2016b, Raven et al., 2011).

This implies conflicts and interpretive flexibility between niche and regime actors. The selection innovations are structured and constrained within the incumbent regime through interpretation by regime actors (Smith et al., 2010) which result in embedded capacity and path dependency mechanisms (Smith and Raven, 2012). This results to some degree in protective spaces for learning processes to strengthen the niche to become part of the regime. Protective spaces are arguably required to protect radical innovations from the selection pressures imposed by incumbent regimes (Smith and Raven, 2012, Schot and Geels, 2008).

It was discussed that the incumbent firms tend to adopt slow incremental processes for technological change within their path dependency and subject to various lock-in mechanisms, such as routines and heuristics, existing skills, prevailing knowledge, incumbent technologies and capabilities, and resources (Smith and Raven, 2012, Scrace and MacKerron, 2009).

This means that new innovations must *'fit'* with the existing structure (selection environment) formed by the incumbent industry or will fail to enter into and to compete with the mainstream market (Smith and Raven, 2012).

This study revealed that it is necessary to create 'new knowledge' beyond the oil and gas lessons, in order for offshore wind technology to be deployed and developed further. This research also found that the experience and lessons that were learned from the incumbent oil and gas industries form a 'socio-cognitive selection environment' formed by incumbent firms which is less likely to be useful in a competitive electricity market.

Scholars suggest that a socio-cognitive protective space allows new knowledge, beliefs, and capabilities to improve and to develop (Smith and Raven, 2012, Smith et al., 2010, Geels and Schot, 2007, Kemp et al., 1998, Rip and Kemp, 1998). For instance, the SNM (strategic niche management) theory provides useful insights into this process. It assumes that building extensive social networks between multilevel actors will leads to robust learning processes to advocate innovations (Geels, 2005b, Hoogma et al., 2004, Kemp et al., 2001, Kemp et al., 1998, Geels, 2005c).

As an empirical example that can be added to this argument, this research found that increased relationships and involvements within the offshore wind supply chains and developers will strengthen knowledge by sharing experience. The empirical evidence in this research showed that establishing extensive 'networking' events between a broad groups of social actors such as supply chain and meet the buyers events are important to build new knowledge and improve skills through 'sharing experiences' and 'best practices'.

It was also found that the offshore wind sector receives support from a number of bodies: Renewable UK is a membership organisation which promotes the renewables sector and engages with politicians and the media, as well as organising annual offshore wind conferences and exhibitions. The Offshore Renewable Energy Catapult is a research centre for sharing knowledge to accelerate the deployment and commercialisation of renewable energy technology innovation, and regional initiatives. In the East of England region, Orbis Energy acts as a hub for the growing offshore renewables businesses, providing a physical space and support for local renewable businesses.

The East of England Energy Group is the industry and skills association for energy producers and their supply chains, providing events, networking opportunities and awards to raise the profile of the sector within the region.

Funded programmes, such as Regional Growth Fund, also help the development of the offshore wind supply chain by providing investment and helping to create jobs. It was also found that collaboration between local authorities such as County Councils and the New Anglia Local Economic Partnership (LEP) help to align the supply chain, to lobby and to provide funding to attract investment and promote the East Anglia region broadly, but also specifically in terms of offshore wind development. These networks have created significant benefits by giving the supply chain access to high level officials both at the central government minister level (Kern et al., 2014) and the regional levels.

These arguments demonstrate that these networking and collaborations between niche and regime (multilevel) actors help to create the *'protective space'* that are necessary for the offshore wind sector to develop.

The findings from this research also showed that 'continuity of doing projects' and 'joint projects' among multilevel actors are key for the creation of new knowledge, *'expectations'* and *'visions'* to stabilise niche activities. These findings demonstrated that networking and collaboration between multilevel actors provide opportunities for broad groups of actors to participate in creating and practicing new knowledge and to enhance learning processes. The findings also lead to better results such as increased capacity and improved performance of 'niche experiments' to be able to stabilise (nurturing) innovations and remove advocates' socio-cognitive protective space. This supports the argument that new knowledge when *'shared and practiced by many actors'* contributes to technology development (Raven et al., 2016, Schot and Geels, 2008).

This study revealed that niche actors take advantage of the existing *spaces* (Raven et al. 2016) such as geographic conditions, and existing knowledge such as transferring skills, technology and prevailing experience to develop offshore wind technology and to perform better in using new technology. Learning processes, path-dependency mechanisms and technological development have been discussed to understand how the development and empowerment of offshore wind can be achieved within the existing system through these mechanisms.

Networking between multilevel actors helps to empower niche configurations to enter into the regime, considering the mobilisation of resources for the niche development and changes to the selection environment. It is also important to include the role of institutional settings (Kern, et al., 2015) in the development of niche processes, therefore, the next section discusses the interactions between institutional settings within the regime level along with niche development processes to complete the framework (Figure 2.4) of this thesis.

5.4 The transition dynamics

This research revealed that the transition to a low carbon energy system, an offshore wind system in particular, is viewed as changes that occur as outcomes of the interplay between and co-evolution of developments at niche, regime and landscape levels (Verbong and Geels, 2010, Geels, 2005d). This means that the transition requires the construction and development of a new technological system at the niche level along with the creation of protective spaces, as well as changes in institutions at the regime level that occur through pressure from the landscape level. Within these development processes, the offshore wind system can empower and break the path from the niche level to the regime and can link up with or change the existing settings, such as incumbent technologies and cognitive rules, which transform the current energy system.

The analytical framework that was developed in this thesis enables the inclusion of niche actors and their experiments (technological innovations) as well as to consider how the niche activities are socially shaped and institutionally embedded within the regime and landscape settings. This demonstrates that there are some links between the research framework and the MLP. Therefore, the next sections discuss the research findings in the light of the transition literature and MLP theory.

5.5.1. Regime developments

This section addresses change in dominant settings that are constrained by the regime's institutions considering *'empowering strategies of niche advocates'* for path breaking niches (Kern et al., 2015, Fuenfschilling and Truffer, 2014). This study found that changes in the regime settings occur through three processes: dominant technology, cognitive and regulative rules, and social networks (Verbong and Geels, 2010).

It was found, and noted in section 5.2, that the energy regime in the UK is locked-in to the current configuration of large scale power generation technologies. Findings evidenced that although utilities switched from coal to gas as result of the dash for gas since the 1990s, still 22.6 % of the UK electricity is from coal fired power plants while offshore wind has a share of 5.1% in 2015 (Table 4.3). This demonstrates a slow incremental change which is caused by technology lock-in within the electricity system.

Although, the offshore wind is beginning to achieve a share (17.4 TW h) of the UK energy mix, this scale may not have significant impact in the wholesale market (Geels et al., 2016). Further technological change within the electricity system depends on how the offshore wind empowering strategies are legitimised in institutional settings.

The empirical findings from this research revealed that the offshore wind sector as an industry is under policy incentive to reduce the cost of energy to become stabilised and to be able to compete with other sources of energy through the introduction of several frameworks such as the Levelised Cost of Energy (LCoE) and the Cost Reduction framework. It was found that, in order to deliver the policy aim in terms of providing an affordable cost of energy and stabilisation in the marketplace, the offshore wind industry needs financial and policy support, as the industry is relatively new and the supply chain is still under development. The data also showed that incumbent energy firms' investments in renewables are through reorientation of their complementary assets and resources towards renewables. These firms have large scale and established technological configurations, a long term market positioning and an established knowledge of the existing electricity market. This is because large scale technological configurations such as the electricity system have a tendency towards inertia because technical components and institutional elements coevolve in order to increase returns over the lock-in mechanisms (Unruh, 2000).

Path dependency and lock-in occur within the system as previous investments affect current decisions in terms of what is viewed as acceptable technical and institutional change. The offshore wind supply chain can be locked out of the electricity system by incumbent firms due to their vertically integrating chains when the incumbent firms choose to maintain the existing settings (Russell, 1993) which are a result of a reorientation strategy (Geels et al., 2016, Geels, 2010). It is interesting to observe that this issue remains unsolved within the offshore wind sector. An example of this lock-in is that Siemens as an incumbent turbine manufacturer for the East Anglia ONE array plans to integrate into installation so taking over Seajack as an expert in vessel jack-up. This implies that the institutional framework including decisions, knowledge and beliefs are dominantly market based and follow an economic positioning strategy ruled by incumbent firms (Geels et al., 2016, Geels, 2014, Verbong and Geels, 2010).

The research findings support Geels et al. (2016) and Geels and Penna (2015), where they suggest that changes in both cognitive and regulative rules are associated with incremental technological change which then influences institutional change. This institutional change is important for a new technology (niche) to gain legitimacy. The empirical findings indicated that forming joint ventures and joint projects between the offshore wind supply chain and incumbent firms (developers) shapes the generation assets by growing the number of vertically integrated partners such as developers, strategic and financial investors. The joint venture and project strategy can enhance both the industry and the supply chain's capability and readiness to improve knowledge and cognition of a new technical system.

The findings showed that cognitive rules within the electricity system influence the regime response to uncertainty over the long term energy policy and market visibility for the offshore wind development. This study found that the cognitive rules as a shared belief system held predominantly by large scale fossil fuel based plants operated by the incumbent Big Six utilities (Kern, 2012), has resulted in a strong network in the form of a coalition between the government and incumbent firms. This explains that there are high regulatory and economic barriers to change the existing technologies due to the formulation of the renewables policy that suits the incumbent firms' interests (Geels et al., 2016).

The empirical findings demonstrated that the CfD is viewed as a 'capacity-centric' policy which focuses on a sizable market while in terms of delivery of offshore wind capacity, the annual auctioning process within the CfD creates uncertainty about the feasibility of investments on development such as seabed surveys, consent and leasing. The guiding principle is to reduce the cost of energy while offshore technology is relatively expensive and thus needs investments in R&D. Under the current regime settings, renewables and particularly offshore wind are therefore required to adapt to market rules oriented by incumbent regime actors.

Cognitive rules are important to decrease the effect of interpretive flexibility between actors in response to guiding principles such as cost reduction (LCoE) and grid parity. The data showed that the success of CfD as a guiding principle for supporting the offshore wind development depends on 'clarity' over cost reduction, market size and scale of projects, and over the wider energy policy. Without regulative support, it is less likely that offshore wind technology can compete effectively with the existing technologies and cognitive rules that dominate the incumbents.

The energy policy in the UK is highly politicised but the niche actors achieve less traction with policy makers (Geels et al., 2016) in terms of influence on decisions. If the offshore wind sector can reduce costs further to reach the parity proposed by the DECC (£100 /MW h), then the cognitive rules may change in favour of offshore wind and it will become institutionalised. As discussed, the offshore wind supply chain is the most viable to reduce the cost of energy, but it is institutionally embedded in existing settings and the regulative rules are not yet sufficient to change this.

It was found that, changes in cognitive and regulative rules require changes in social networks between multilevel actors. As discussed above, niche actors are unlikely to gain power over regime actors. This explains why changes in social networks are required as part of regime development. The findings revealed that the existing social networks within the electricity sector are stable and part of the regime lock-in mechanism. So attracting new entrants, such as investors and developers into the existing regime, means responding to change in the system towards a low carbon system (Geels and Schot, 2007, Geels and Raven, 2006, Geels, 2004b).

The findings showed that within the existing social networks, there are some areas that social actors align their resources and activities through, for example a selection of projects and best locations, and by driving innovations through the sector in terms of technology choice and bringing down costs to a more affordable level. This explains the importance of the supply chain to reduce costs. It is realistic to assume increasing collaboration and interaction between regime and niche actors within the existing social networks but there is still some degree of uncertainty. The CfD is still under development within institutional settings, which affects the activities and prioritising of the current social networks depending on the perceived effect of wider policy and economic factors at the landscape level.

5.5.2. Landscape pressure

The landscape level of the electricity system places pressure on the existing regime to form institutions that consist of cognitive and regulative rules. It was found that the landscape level influences the development of the offshore wind system through macro-political developments and macro-economic trends.

This study found that the UK macro-political context for the low carbon electricity system is based on the economic growth objectives such as increased market capacity and jobs creation. The electricity market is ruled by regulatory incentives. This means that market actors (regime actors) cannot directly influence the market direction, but can perform where market imperfections are observed, such as climate change targets (Kern, 2012, Shackley and Green, 2007, Stern, 2008, Lauber and Jacobsson, 2016, Jacobsson and Lauber, 2006, Mitchell, 2008). This research shows that climate change and energy security concerns have become increasingly prominent factors under which the macro-political context destabilised the existing regime in terms of capacity and policy framework (Kern, 2012, Shackley and Green, 2007).

The data revealed that since 2008, when the government committed to the EU202020 targets, several UK based policies have adopted those climate change targets such as the Climate Change Act as a radical policy change (Carter and Jacobs, 2014). There has also been the introduction of the Renewables Obligation (RO), and the Electricity Market Reform, which provided motivation for large scale renewables such as offshore wind and nuclear power. More recently, there was the introduction of the Contract for Difference (CfD). Further to these commitments, the Department of Energy and Climate Change (DECC) and the interdependent Committee on Climate Change (CCC) were established in 2008 as the government agencies to monitor progress towards climate change targets.

The macro-economic trend affecting the renewables support policies, in particular for offshore wind, has been influenced by the effects of the financial economic crisis of 2008 and the UK economic recession. The political response to the economic crisis created concerns about jobs (Kern, 2012) and energy prices as two key ambitions that added to the government agenda, taking preference over climate change policies (Carter and Jacobs, 2014). Concerns about jobs and energy prices caused by the financial economic crisis have influenced the green policy agenda (Carter and Jacobs, 2014) and long term renewable electricity targets beyond 2020 (Geels et al., 2016).

The economic conditions and austerity have driven several socio-economic trends that create political uncertainty over prioritising goals. The findings evidenced that energy policy uncertainty at the landscape level influences the development of offshore wind by affecting the support for niche technologies provided by regime actors including the availability of public funding for investment in new technologies, subsidies for further CfD auctions and skills development. Overall, energy and electricity policies have shifted towards a more interventionist approach (Geels et al., 2016, Kern et al., 2014, Lockwood, 2013).

5.5.3. Niche legitimacy

It was found that deployment of large scale renewables under RO accelerated from 2008, with renewables gaining 25% and offshore wind in particular reaching 5.1% of total electricity generation in 2015. This growth was made possible through coalitions (networks) of large firms and policy makers (Geels et al., 2016), the creation of new knowledge through learning processes, early market experiments the wider legitimacy of renewables for electricity generation (Smith and Raven, 2012). The interactions between the regime and wider landscape can nurture offshore wind technology. Using the SCOT theory insights, it is shown that the offshore wind system is embedded in broader social institutions and practices.

Also, this study found (as discussed in section 5.5.2) that social interactions can incentivise political strategies to change institutional settings which results in both the creation and empowerment of offshore wind technology. These arguments explain that although radical technical innovations often have relatively low legitimacy (Schot and Geels, 2008, Rip and Kemp, 1998), social interactions through networks and learning processes (learning from experiments, sharing knowledge and creating new knowledge) create socio-cognitive protection for offshore wind which leads to wider institutional legitimacy (Smith and Raven, 2012).

The increase of offshore wind legitimacy will attract further support from the regime actors. Increased legitimacy may also open up social networks providing greater stability for niche actors. The empirical findings showed that interactions between multilevel actors have occurred through social events such as the Renewable UK annual offshore wind conference and exhibitions, and supply chain events.

Although incumbent energy firms responded to the offshore wind market, the 'capacity centric' nature of CfD prevents new entrants (niche actors) from stepping forward. It was found that partnerships such as joint projects and joint ventures are potentially significant solutions for both the development of the offshore wind system and increased interactions between the supply chain (as niche entrants) and the incumbent firms. The events and partnerships contribute to building legitimacy for offshore wind.

Once niches are fully developed to be able to commercialise a new technological innovation in the mainstream market as a result of social interactive mechanisms, they can build momentum to improve prices, increase capability and increase performance to allow a socio-technical transition.

5.5.4. Interaction of niche, regime and landscape

This study revealed that the scope with which a niche can challenge the incumbent regime through various interactive mechanisms depends on the effects of developments at the landscape level associated with the regime's response to these processes. As discussed, climate change and energy security are main external concerns which place pressure on the current regime to find sustainable solutions for decarbonisation of the electricity system. Climate change and energy security are ongoing issues that require a long term plan for future energy generation and supply.

The UK commitment to EU 202020 in 2008 coincided with an economic recession from 2008 which led to different decisions and priorities to emerge, affecting the landscape and electricity policy. The policy landscape has been changing over time because the landscape processes involve multiple decisions in terms of prioritising technology options over time. This may increase politicisation and negotiations which leads to conflict over the decision making, resulting in a delay in transition processes. Within the electricity system, politicisation leads to uncertainty in policy due to multiple views and expectations in terms of the size and competitiveness of the market, the scale of projects and potential options for market growth beyond 2020.

The decarbonisation of the electricity system with regard to renewable policy is currently uncertain due to the uncertainty of the future of CfDs. Also the decarbonisation of the electricity system is highly politicised over renewables, such as gas and nuclear. This argument is in contrast with the notion that external *'shocks'* shape the development of institutions proposed by Geels and Schot.

Taking insights from political science, Thelen (2003) provides useful insights to which new institutions can develop as a layer of the existing settings through incremental adjustment while the principals remain unchanged (Mahoney and Thelen, 2010). Within the existing regime, climate change and energy security are long running issues in which institutional change requires long term planning based on policy learning.

Transition may therefore have different pathways depending on the timing of landscape pressure on the regime and the degree of development of niche innovations (Geels and Schot, 2007).

5.5 Transition pathways

In previous sections, the processes which affect the development of the offshore wind system were discussed. This section discusses possible transition pathways in the UK energy regime in light of the research framework. This study revealed that a transition occurs when a new societal function which is the outcome of interactions of the three analytical levels: niche, regime and the landscape, become socially institutionalised and gain legitimacy over the existing institution settings in a socio-technical system. Change in institutions entail conflicts between incumbent actors and niche advocates and involve intervention and interaction mechanisms to facilitate this change (Geels et al., 2016, Mahoney and Thelen, 2010).

In the electricity system, in terms of technological change, this study found that offshore wind technology has been developed based on the improvement of onshore wind technology and a transfer of technology from other offshore industries such as oil and gas. These incremental processes develop through learning processes within existing technologies and lead to integration and creation of new knowledge to accumulate technological improvement (Geels, 2006a, Bergek et al., 2013, Geels et al., 2016).

The empirical findings confirmed that radical innovation has speed up processes of technological improvements within the offshore wind sector. For example there has been a new generation of high performance turbines (7-8 MW capacity) equipped with helipads. It was found that, radical innovation in turbine technology has led to more cost effective solutions and new technology capability in terms of fewer installations, reduced maintenance costs and improved production.

The empirical data showed that social actors believe that if energy firms change their business models to enable the cost of technology to be reimbursed, then production costs can be further reduced. This supports the technological capability in terms of price and performance improvement which is the focus of policy makers (regime actors).

With regard to actors, it was found that a lot of the oil and gas operators and developers diversify their strategies to invest in the offshore wind field, as well as operating nuclear power stations, biomass power stations, gas fire power stations, and onshore renewables. This diversification and reorientation towards radical innovations incentivises incumbent firms to change their strategies further which result in a decrease of the effects of lock-in processes that is assumed in the MLP theory (Geels et al., 2016).

Also, in terms of institutions, the concept of the Electricity Market Reform creates more favourable incentives for large firms through CfDs with regard to large scale renewables deployment. While auctions and trading schemes create more uncertainty, only incumbent firms can cope with this ambiguity. These arguments confirm that the focus of policies and institutions are predominately on incentivising large energy firms to deploy large scale renewables such as offshore wind technology (Kern et al., 2014). Although, new technology requires new knowledge, it is interesting to observe that the new knowledge must reasonably fit with the incumbent firms' business models and guiding principles which explains why offshore wind is mainly enacted by large energy firms.

Referring to the transition pathway typology proposed by Geels and Schot (2007) and Verbong and Geels (2010), this part discusses the outcomes of arguments to illustrate the possible pathways within the energy regime.

With regard to transition processes that were discussed in this chapter, the development of the offshore wind system within the existing regime, in terms of technology, seems to form a *'transformation'* pathway since the development is both based on incremental improvement of incumbent technologies (onshore wind and offshore oil and gas technologies) and a reorientation towards radical innovation (high performance turbines).

However, in terms of institutions, new policies emphasise the creation of a competitive market in terms of size and scale of projects in which the development of offshore wind technology must *'fit-and-conform'* to the existing institutions. Policies that support the co-existence of coal (with 22.6% of total electricity generation in 2015) with renewables in the energy market represent a layering pattern in which new settings follow the incumbent logic.

These arguments collectively imply that in terms of institutions, the current regime forms a *'substitution'* pathway. In terms of actors, vertical collaborations between incumbent actors and the offshore wind supply chain in the form of sharing knowledge and joint projects, shapes a *'reconfiguration'* pathway. These shifts between pathways make the transition unfocused and slow. This is because policies are formulated based on a favourable fit with incumbents' reorientation technologies and so create barriers to new entrants whose focus is only on renewables. Finally, incumbent firms always have the opportunity to vertically integrate in any parts of the supply chain and create a value chain with their complementary resources.

5.6 Framework

The research framework that was developed throughout this thesis explains the interactions between actors, institutions and the offshore wind system for analysing long term socio-technical change and usefully combines insights from the MLP theory and social constructionist approaches. The findings chapter (section 4.1) explained various interactions between institutions and the development of the offshore wind system within the processes of change in the electricity system whilst takes into account the role of actors in these processes. The framework describes the multiple aspects of the interactions between actors, institutions and the development of offshore the wind technology within the electricity system. Table 5.1 summarises the research framework.

Table 5. 1 Summary of interactions based on the research framework

Actor	Institution	Technology
Niche takes advantage of existing resources	Limited institutional change in the form of layering	Technology improvement based on transferring technology and skills from existing technologies
Incumbent energy firms reorient incrementally through complementary adjustment and path dependency Niche actors gain experience through learning processes	Limited institutional change forms fit-and-conform environment for niche innovations to compete in regime selection environment Niche-regime social networks start to shape with less niche traction Niche becomes institutionalised	Slow incremental change in existing technology
Niche-regime vertical collaboration, energy firms take advantage of niche experiments	Broad social networks of multilevel actors New visions and business models start to shape throughout socio-cognitive learning processes Niche gains legitimacy	Technological improvement
Energy firms reorient to radical change through vertical integration with incumbents Niche supply chain locks out from incumbents' integration	New institutions shape through negotiations/ coalition between energy firms and policy makers	Technological change towards radical innovation

Source: Author

5.7 Conclusion

This chapter illustrated the processes underlying the interactions between actors and institutions that helped to explain the development of offshore wind technology. It was found that the existing literature along with a combination of social construction of technology and transition theories to a wide extent can help to illuminate many aspects of these processes. It was found that technological change across the existing regime is a contested process that is influenced by 'multilevel' actors considering multiple interpretations and framings. It was demonstrated that institutional change should also be attached to the structure of the electricity system in processes of technological change within the energy regime as the nature of this interaction is viewed in different phases of the offshore wind development.

In the early stages of development, the transferred technology and skills could shape changes. As the system becomes institutionalised this support is challenged by incumbents, because as the system grows, the institutional framework (including decisions, knowledge and beliefs) becomes more attached to an economic positioning strategy which is ruled by incumbent firms. Further technological change within the electricity system depends on the how the offshore wind empowering strategies are legitimised in institutional settings. This chapter argues that offshore wind shares many aspects of a socio-technical system. Social interactions through learning processes and extensive networks, where experiences are shared by a range of multilevel social actors, can play an important role in constraining change, as these social interactions create a socio-cognitive shield for the offshore wind system which results in increased institutional legitimacy.

Taking insights from transition theory, the degree to which the incumbent regime responds to niche development is influenced by the landscape pressure. It was found that the incumbent regime's (energy firms and policy makers) response to the landscape processes in shaping institutions is highly politicised. For example, while the decarbonisation of the electricity system is a target, more economical options, such as gas and nuclear or combinations of technologies may achieve greater policy support than offshore wind. These multiple options cause multiple decisions and interpretive flexibility which results in an uncertainty in electricity policy.

The politicisation of electricity policy affects the interactions between the niche, regime and landscape levels, which results in different types of socio-technical pathways. It was argued that due to the nature of the electricity system, transition to a low carbon system with regard to offshore wind system, requires shift between the transformation and substitution pathways.

Chapter 6: Conclusion

6.0 Introduction

This thesis constructed new insights into the analysis of the processes of socio-technical transitions. The thesis looked at the decarbonisation of the electricity system by addressing the multiple factors that affect the development of offshore wind technology within the incumbent energy regime. The research framework was developed to reflect the interactions of a number of elements (technology, social actors and institutions) of a socio-technical system to address gaps in the literature, with offshore wind as the focal technological system. This research argued that technology is embedded in its social and institutional context and therefore the development of a technological system needs changes in social actors' cognitions and institutions. This means that technology or technological system is socially constructed and institutionally embedded in its context.

This final chapter of the thesis draws these insights together to highlight the contribution to knowledge that this thesis has made, followed by the policy implications of the research, recommendations, limitations, and suggestions for future research.

6.1 Contributions of the thesis

This thesis makes a contribution to knowledge by uncovering the socio-technical characteristics of the UK offshore wind system within transition processes towards a low carbon electricity system. A study of the socio-technical aspects of a new technology development provides a novel perspective to existing studies and opens horizons to extend knowledge that tends to receive less attention than the technical and policy aspects. This research has contributed a conceptual understanding of the dynamic process of offshore wind development, which consists of unique institutional and technological characteristics within the sector.

Throughout the thesis it has been argued that using transition theory (the MLP) alone is not sufficient for the analysis of the offshore wind system in the transition processes within the energy sector. In response, this thesis combines and integrates two theoretical perspectives: interpretive evolutionary and constructive actor-centric approaches are used within the research framework to provide a significant theoretical view of this topic. Overall, this thesis contributes theoretically, methodologically and contextually to the literature, as summarised in the next sections of this chapter.

6.1.1. Theoretical contributions

This research identified the significant characteristics of offshore wind system and its embeddedness with the availability of natural resources, with social actors in the supply chain, with technology and with institutions (policy and market). The research showed that the electricity system operates as a market based system. Taking insights from Verbong and Geels (2010), this research argued that the electricity system is in a transition phase to even a more market-based system, shaped by negotiations and coalition through social networks from traditionally technology based rolled by engineers. These results evoked some conceptual challenges that needed to be addressed in order to uncover the socio-technical characteristics of the offshore wind system and to form a coherent theoretical concept.

Therefore, the first objective and the contribution of this research was to design a framework to enable the analysis of conceptual factors that affect the transition to a low carbon electricity system and the development of the offshore wind system. As discussed throughout the thesis, the nature of institutions in shaping a new socio-technical system, like the offshore wind system, was a central concern in developing the research framework, while the role of social groups of actors in institutional change were also identified as an important concern. In order to address these concerns, a coherent ontological perspective was established.

It was argued that changes in institutions depend on social actors' cognition (socio-cognitive learning) that is created and shared through their social networks. This shows that institutions are seen as *'inter-subjective'* social reality (Geels, 2010) and are created and institutionalised by multilevel actors through interpretive (negotiation and coalition) processes. Therefore, this indicated the important role of social actors in changing institutions and shaping socio-technical change in the electricity regime. Furthermore, technological change (improvement) is institutionally embedded through a series of social interactions. These insights also improve the ontological perspective of the MLP which is criticised for being a flat ontology.

These interactions are explained by the three analytical levels within the MLP: niche-innovation, socio-technical regime and the landscape, which shape transitions. The regime level provides scope to analyse how the development of niche practices interact with incumbent regime structures. However, the MLP is unable to analyse the interpretive role of actors within the processes of transitions.

The role of actors is vital in sense making and the socio-cognitive learning that lead to the legitimacy of new technology as form of niche practices and their institutionalisation accordingly. This problem is tackled in this research by using SCOT theory as a constructive approach which highlights the entrenchment of beliefs incorporated within the processes of a socio-technical transition.

The integration of the MLP and SCOT theories is achieved by considering the electricity system at the socio-technical regime level, while the offshore wind system, which contains its own components, is regarded as a new socio-technical system at the niche level that needs to be developed and empowered towards the regime level. Although SCOT theory is criticised for its lack of analysis of new technology (Geels, 2004b) and its empowerment to the regime level, the combination of the MLP and SCOT is shown by this research to be appropriate to uncover the socio-technical characteristics of the offshore wind system within transition processes.

These theoretical insights were incorporated into a coherent analytical framework which was developed to frame the research and to extend knowledge and the understanding of the socio-technical transition towards sustainability by applying it to the electricity system. Therefore, the research framework demonstrated how a socio-technical system is created (or integrated based upon the existing system) through the ongoing interaction processes between technology and institutions that are socially embedded in material (technical), social networks and, cognitive and normative dimensions (Verbong and Geels, 2010) of the system. Each element of the framework (technology, actors and institutions) collectively acts in multiple dimensions rather than in a linear path such as barriers to a new socio-technical system formation like offshore wind. The discussion chapter argued that this framework can bring together niche-regime and regime-landscape analyses. In addition, the research framework provides further analyses of the outcomes of interactions between social groups of actors, institutions and technology development.

To sum up, from the interpretive perspective, this thesis has made a distinct contribution to knowledge by showing how Geels' MLP framework for analysis of the transition processes can be fruitfully incorporated with Bijker and Pinch's constructive SCOT approach to help to explain technological and institutional change by studying the interactions between socio-technical system elements: technology, institutions and social groups of actors.

The research framework that was developed by this research confirms the constructive/ interpretive role of social actors in technology and institutions changes to develop a low carbon socio-technical system within the existing system. The analysis also showed that the networking of social actors is important for the processes of legitimacy and institutionalisation of a new socio-technical system which is rooted in visions and beliefs, as well as, in creation new knowledge.

The analysis corroborated the interaction mechanisms of the niche-regime that explained elsewhere in transition studies (MLP), for example Geels (2010) and Verbong and Geels (2010), are included the constructive/ interpretive role of actors that has been neglected in these literatures. The thesis explained these interactions by using the research framework to identify the transition pathways for the electricity system within the socio-technical transition that highlighted different possible pathways. Therefore, the evidence provided in this thesis improves our understanding of the interactions of socio-technical system elements and thus contributes to scholarly debates within transition studies.

6.1.2. Empirical contribution

The key empirical contribution that this thesis has made is in the understanding of the socio-technical elements of the offshore wind system in the UK. It was argued that the extant literature mainly focuses on the technological aspects of the offshore wind system in an analysis of the existing regime during transition processes. Since the development of the offshore wind system becomes an increasingly important part of the UK energy mix in generating low carbon electricity, it is argued that by considering the role of social networks and making the interactions between multilevel actors a central focus, the thesis enables and provides novel insights into the analysis of the transition to a low carbon electricity system.

This thesis makes a distinct empirical contribution by analysing the effects of the CfD, which is being practised for the first time within the offshore wind sector, on the development of the offshore wind system in the UK electricity system. It was argued that within the system there are also social networks, economic and institutional aspects that are important in shaping the effects of the CfD mechanism. The introduction of CfD fits with the large scale nature of offshore wind, therefore, the rationale behind this was to reduce the costs of energy.

While costs can be addressed in a stable and sizable market (where niche-innovations can be practiced and shared), it is clear that a long term energy policy, providing certainty, is required to establish a stabilised market. The offshore wind sector is trapped in a dilemma of two interdependent elements: a long term policy view and integrating a sizable market. This research found that large incumbent energy firms do have the courage to invest in such a large scale project (which helps the overall of the offshore wind development) through their resources and vertical integration.

The East Anglian coast specifically and the UK more generally have noticeable potential for offshore wind growth in terms of natural resources. The development of offshore wind is also economically efficient as it has the potential to create jobs and boost the local economy accordingly.

The study of UK offshore wind development highlights that offshore wind technology has been developed through the modification of onshore technology and by transferring some technology and knowledge from the offshore oil and gas sectors. In particular, skills and experience in installation, seabed studies, transmission, crew transferring, and some lower level Tiers (supply chain) have been transferred from the oil and gas sector to offshore wind. This brings additional economic benefits to the deployment and development of offshore wind as a low carbon technology, but it involves multilevel actors who tend to have different visions and requirements which may be in conflict with each other.

It is proposed that for the development of the offshore wind system, the incumbent energy policy frameworks (regulative rules) need to be changed. In doing so, it is important that policy makers and incumbent firms build a more extensive social network with the supply chain (as niche actors), in order to create new knowledge in the form of the institutional and technological characteristics for the offshore wind. Therefore, it is essential to establish coherent visions and goals and clarity throughout the social networks and between multilevel actors. The analysis of the interactions between multilevel actors and multiple factors contributes to a deeper understanding of the development of the offshore wind system within the process of transition to a more sustainable electricity system.

6.2 Policy implications and recommendations

The research framework provides an analysis of the role of social actors in relation to technology and institutions. It provides deeper insight into the understanding of the role of the actors that affect these interactions to inform the socio-technical transition towards a more sustainable electricity system. Energy policies seek to promote the transition towards increased sustainability and a low carbon energy system (of which electricity is a part) due to the institutionalisation of climate change concerns.

Sustainability is characterised by a normative goal and a sustainability transition within the energy domain that involves multiple *'green'* niche-innovations (Geels, 2010), of which offshore wind is one out of a variety of possible solutions. It was found that UK offshore wind development has flourished as the UK's natural resources make it more feasible than other renewable sources (Kemp, 2001). However, it was found that the development of offshore wind technology requires high capital investment and so typically depends on public subsidies.

With regard to the effect of the policy framework on offshore wind development, it was found that UK energy policy and the CfD in particular made a difference by providing the conditions for particular configurations (i.e. large scale installations) and for reducing costs. It was argued that large firms with experience of energy operations are more likely to be able to respond to these conditions than smaller firms operating at the niche level. It was also argued that policy objectives emphasise energy cost reduction, by upscaling the output of the projects, such as by operating larger wind turbines, and increasing the size of the market requires appropriate energy policies to be implemented. Although large incumbent energy firms are able to deliver the government objectives, the development of offshore wind requires further regulative support, which is largely shaped by long term decision-making which needs to be integrated into policy and regulation processes.

It was argued that the interactive mechanisms and socio-cognitive processes between incumbents (which includes government agents and energy firms) and niche actors shape social networks, which are important for sharing knowledge for the development of offshore wind system. It was also argued that the success of CfD (as a guiding principle) depends on how to provide ‘clarity’ over cost reduction, market size and scale of projects, and over the wider electricity policy which can be achieved through extensive social networks.

It is unlikely that the current cognitive rules can significantly facilitate the development of the offshore wind system while the existing social network is stabilised within the electricity regime and politicised over incumbents’ decisions. On the other hand, the CfD is still under development and the future of subsidy is uncertain (for example the second CfD auction has been postponed), so its effects on the current social networks depend on the effect of wider policy and economic factors at the landscape level. Therefore, changes in both cognitive and regulative rules are required which link with changes in the social networks of wider and multilevel actors.

In order to value the contribution that the more extensive social networks can make in the implementation of the new policy, the analysis highlighted the important role of both incumbent and niche actors. It was argued that the focus of policies and institutions are rather on incentivising large energy firms to deploy large scale offshore wind projects and to reduce costs. This encourages the incumbent energy firms to diversify into the offshore wind field. Therefore, the implementation of the new energy policy, CfD in particular, for the development of the offshore wind system involves an alignment between firms’ strategies and wider policy goals.

However, collaboration (both in learning by doing and in promoting socio-cognitive learning) in a wider social network between the offshore wind supply chain (as niche actors) and the incumbent firms (as niche advocates) are suggested to make changes in policy formulation against the barriers that reorientation strategies create to niches. This interconnection will not only require resources (for example skills and technology) and capacity (performance) development within the supply chain, but also the development of more coherent institutional settings at the sector level which promote standardisation, experience, continuity, and sharing of best practices. Associated with this, the role of multilevel actors in incentivising innovation in different parts of the sector and incorporating this into the current regulatory process needs to be promoted.

6.3 Limitations and avenues for future research

This thesis has made significant contributions to the literature from several aspects. This thesis has focused on the UK context and the East Anglia location in particular. It was decided to take the system level approach rather than focusing on a particular wind farm or a developer in order to capture more generalizable findings related to the effects of interactions between technology, institutions and social groups of actors within socio-technical processes on the development of the offshore wind system at a national level. It was also decided to focus on contemporary and ongoing activities for offshore wind development, rather than looking at historical cases in order to provide novel insights regarding recent decisions and regulations that affect the socio-technical transition processes. On reflection, the semi-structured interview provided valuable insights for the ongoing processes of the development of offshore wind and the associated barriers and opportunities.

The semi-structured interviews provided a diverse set of empirical findings and the qualitative analysis provided a deep understanding of the transition processes in the electricity system, by evaluating multiple factors including external pressures and the interpenetrations of different elements: a range of interactions between multilevel (niche-regime) actors, institutions and technological change. The researcher put considerable effort into including most influential actors, representing each of the key social groups across the sector, but not all of the actors approached were able or willing to give their time for this research. In many cases, they did however provide reports and presentations relevant to the research instead. This research may therefore not have drawn on all actors in the sector, but the researcher is confident that all key social groups were included and a wide and diverse range of views were collected during the research process.

Another limitation is the newness of the CfD, which was practiced for the first time during the timescale of this research, as explained in chapter 4. It was observed that there were less insights into the implementation of this policy due to its newness. Therefore, the empirical findings related to policy could be further developed in future research by making comparisons between the evolution of energy policy in other countries with different maturity levels for policy on offshore wind development and for different goals for long term carbon reduction such as in Denmark and the Netherlands. Such empirical research would further strengthen the arguments and recommendations developed in this thesis. By comparing other well-practiced policies, there could have emerged an incentive policy recommendation for the UK. However, conducting an international comparative study was not applicable due to the limited time available for this doctoral study and a lack of certainty in terms of the availability of and access to relevant participants.

The thesis focused on one source of renewable energy, offshore wind, so the framework is specifically developed for the analysis of the development of offshore wind sector. Therefore, another area for future research would be to explore the operationalisation of the research framework to other renewable energy sources relating to the transition to a low carbon energy system, for example solar energy and tidal energy developments. The validity, robustness and generalisability of the framework would also be strengthened by addressing real world problems drawing on issues from multi-disciplinary perspectives, for example by operationalisation the framework in other domains such as transport or transmission. Another policy related suggestion would be to analyse the impact of Brexit, and the UK leaving the European Union on inward investment for the offshore wind projects, future subsidies, UK market proximity and continued market leadership.

It is reasonable to assume that transitions for other sustainable or low carbon technologies, such as onshore wind, tidal and solar energy would experience similar interactions between elements of the socio-technical systems as for offshore wind. However, these assumptions of generalisability would need to be tested by future research into these other domains.

Appendices

Appendix 1. Consent form

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Tel: +44 (0) 1603 592263
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PARTICIPANT CONSENT FORM

Title of Research:

The Exploratory Study of Wind Energy Development within UK Energy Regime Transitions

Name of Researcher: Jila Bagherian
1.04 TPSC
Norwich Business School
Email: J.Bagherian@uea.ac.uk
Mobile: 07453595588

I confirm that I have read and understood the information sheet for the above study and have had the opportunity to ask questions.

I understand that my participation is voluntary and that I am free to withdraw at any time partially or completely from the process, without giving reason.

I agree to take part in the above study.

I agree to the interview being audio recorded.

I agree to the use of anonymised quotes in publications for the purposes of the research.

I understand that my comments will be anonymous and my identity known only to the above named researcher.

______________________	______________	______________________
Name of Participant	**Date**	**Signature**
______________________	______________	______________________
Name of Researcher	**Date**	**Signature**

Appendix 2. Participant information

University of East Anglia

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PARTICIPANT INFORMATION SHEET

Dear Sir/ Madam,

Miss Jila Bagherian

The above named student is a registered PhD research student at the University of East Anglia and she is researching 'the factors affecting the development of wind energy in the UK and New Anglia'. The research is expected to identify and understand perspectives from different stakeholders in the energy sector.

Your participation will involve being individually interviewed to understand your perspectives on the development of the wind energy sector. The interview will be audio recorded and subsequently transcribed. All interview data in this study will be treated in the strictest confidence and will be anonymous. This follows standard ethics procedures and any data will only be used for the purposes of Jila's research.

You may contact the research supervisor, Prof. Fiona Lettice, either on this email address (Fiona.Lettice@uea.ac.uk) or telephone number +44 (0)1603 59 2312 for questions about the research.

You will be more than welcome to see the final results of the research when it is completed.

Thank you for your cooperation and assistance.

Yours sincerely,

Main Supervisor	**Co-Supervisor**	**PGR Director**
Prof. Fiona Lettice	Dr. Konstantinos Chalvatzis	Prof. Karina Nielsen

Appendix 3: Sample interview questions

These questions were used as basis for interviews. However, these questions were modified to each participant. Therefore, additional questions were included to cover topics that discussed in each interview.

1. Please introduce yourself and your responsibility in xxx?
2. What is your opinion on the importance of the development of offshore wind technology for the generating of electricity in the UK?
3. What are the barriers that face energy organisations and the supply chain within the energy sector in the processes of offshore wind development in the East Anglia region?
4. How these barriers can be improved and facilitated the offshore wind projects?
5. How does xxx support the offshore wind energy supply chain?
6. What do you think about the role of national policies and regulations in the deployment of wind projects?
7. What is your opinion about ‘cost reduction programme’? How does this programme impact on industry particularly developers to market entry?
8. What actions will xxx take to implement these policies and are there any specific actions that have already taken?
9. As holding a key position, how do you perceive the effect of policies on investment on the development of offshore wind projects?
10. Please feel free if you want to add any further comments.

Appendix 4. Examples of findings and analysis table

Code	Theme		Quote	Source
Innovation	re-skilling and re-training programmes		‘‘We work a lot with the military to help them understand how their skills transfer and that will either be mechanical engineering or electrical.’’	En.L5
	Efficiency in operation and maintenance		‘‘There are lots of different ways of improving and making things more efficient. So making the turbines bigger you need to put less of them in, changing the technology what we are doing is looking at the operations and maintenance side of things and managing all of the personnel, fuel use of the transfer vessels.’’	EG
Market	Cost	Cost competitive and Grid parity	‘‘Cost comparison with nuclear which £93 per MW h are we going to reach that parity? Absolutely yes- perhaps by 2023 if not before will be cost competitive with nuclear power. Actually offshore wind technology is evolving.’’	En.L2
		Market visibility	‘‘We are faced, therefore, by a dilemma: Government will only provide for a sizeable offshore wind market if it has confidence that costs will drop significantly, but industry will only invest to reduce costs if it has confidence in the long term future of the offshore wind market.’’	D1
	Size and potential and opportunity for growth		‘‘Obviously the amount of offshore wind on the system is increasing year by year, well, month by month and we have got 5 GW on at the moment and we will have 10 GW by 2020. So it is having a profound effect on the energy mix.’’	P.N5
Policy	Policy certainty		‘‘Policy is the first barrier that has to be overcome. If there isn’t the political will to do so then we will see that this trance of projects over the next few years are the end, unless the costs come down so much. But even then that still doesn’t guarantee anyone will still get the right to build any further.’’	C.L4
	CfD effects		‘‘if the people developing offshore wind now had known 5 or 6 years ago when they took the Round 3 development zones on, they wouldn’t even have started because it makes no financial sense to spend 50 million quid getting something through the consenting process, getting it all designed and ready to build […] but no contract to build.	SC5

			And what do they do – they have to wait for government to say that next year there might be some more contracts? The danger is that if they can't see the future they will have to pack up and go home''	
	The role of local authority		''One of the things we [local authority] were keen to do was to identify the barriers that would prevent the businesses coming here. [for example] We are taking measures to put flood protection barriers in place. So that when the businesses do come here they are not at threat of being flooded out which they just couldn't, could not afford to do […]''	P.L3
Supply chain	Networking and collaboration		''Different developers manage projects in entirely different ways. […] The result is that there isn't a single place for anybody in the supply chain to go to and to say this is what we can offer and it is also very difficult to have a standard way of being invited to tender and prequalify for a tender.''	C.L4
	Learning processes	Support from incumbents	''Obviously getting people to invest in offshore wind is really important. The developers don't have enough money, they haven't got enough funds on their balance sheets to be able to finance these wind farms by themselves. […] a two billion euros wind farm is too expensive for most developers. So we need to attract investment into our offshore wind farms.''	SC9
		Sharing best practices	''Partnerships should be formed between industry and academia in order that relationships can be established. This established relationship means that when a piece of research highlights a possible benefit to industry it is much easier for dissemination without suspicion. Without established relationships there are always barriers to dissemination.''	AC2
	Improve specific skills	Health and safety	''It is a very specific industry, it has got some very specific health and safety requirements as well but that area does seem to be being funded either by the government or by the developers themselves. That is being seen and supported and seen quite visibly and helping to develop skills within that particular supply chain.''	En.N4

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