Skill Requirements of the Low Carbon Transition

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Finally, I would like to apologise to everyone and everything that has been ignored because of the thesis - I hope to return to normality soon.

Table of Contents

Table of Tables

Table of Figures

Abstract

If the UK is to avoid the catastrophic impacts of climate change a low-carbon transition (LCT) must be achieved, whereby our energy infrastructure and economy dramatically reduce carbon-dioxide emissions. The thesis argues that the UK construction sector is key to the success of the LCT and proposes some longer-term skills forecasts to assess whether future supply will meet demand.

The thesis uses secondary data to examine features of the UK construction sector which make it essential to achieving the LCT by building and installing the low-carbon infrastructure. Existing construction skills forecasting methodologies are reviewed to determine the required properties for the long-term projection. A novel model where underlying activity, technical change and institutional change co-evolve is developed to frame forecasts of the demand and supply of skills necessary for the LCT and identify if any potential skills shortages could disrupt it.

To predict long-term UK growth patterns a new approach - Multi-channel Singular Spectral Analysis - is employed, using educational and demographic forecasts and incorporating business cycles. Technical change is explored using four Government produced 2050 pathways, each proposing a differing bundle of technologies to deliver the LCT. The skills demand for each pathway is then forecast and evaluated. Additional forecasts cover other potential demands and the impact of institutions. In particular, the additional impacts of adaptation measures and the possibility of building more dwellings to meet growing demand are evaluated.

The results suggest that given appropriate policies and if the impacts of recessions are minimalised, and the number of new construction workers continues to grow, shortages can be avoided. UK skills policy and training, currently based on an employer-led philosophy, is evaluated to determine if it can provide a timely response to the increased demand for construction skills or whether a more proactive approach is required.

The thesis argues that, if a more proactive engagement by the construction skills institutions and policy makers is adopted, the supply of skills could be sufficient to achieve the LCT. However, the higher levels of adaptation measures combined with building sufficient dwelling to meet demand could produce destabilising addition demand on the construction sector leading to problems with the LCT.

1 – Introduction and Summary

1.1 Introduction

Achieving a Low-Carbon Transition in the UK and elsewhere has been identified as essential for avoiding destructive global warming as well as economic and environmental catastrophe (Stern, 2015). This thesis, therefore, addresses the following question:

1. Could construction skill shortages disrupt the low-carbon transition in the UK?

In addition to this question, and in order to help answer the central question, a series of subsidiary questions are also posed. These are:

2. What features of the construction sector pose a problem for the LCT in the UK?
3. What is an appropriate theoretical approach to understanding skills shortages?
4. How will the economy and associated levels of construction activity impact on the demand for construction skills?
5. How will a range of low-carbon and other technology-driven initiatives additionally impact on the demand for construction skills?
6. What is the potential impact of a range of institutional scenarios on construction skills demand?

These supplementary questions provide the basis for the methodological outline and thesis structure contained in the next two sections.

1.2 Thesis structure

The structure of the thesis follows the research questions to answer these research questions. Therefore, there are five further chapters, in addition to this introduction. These chapters deal with the following issues:

Chapter 2 - covers why the construction sector is important to the LCT - and aims to answers research question number two

Chapter 3 - provides a theoretical underpinning for the causes and consequences of construction sector skills shortages - and aims to answer research question number three.

Chapter 4 - builds on forecasting techniques to provide a forecast of construction activity to 2050 - this aims to answer the research question number four.

Chapter 5 - uses a series of DECC 2050 pathways to explore what additional problems meeting the low-carbon targets could cause for the construction sector - this aims to answer research question number five.

Chapter 6 – uses a different set of institutional scenarios to investigate the potential impact on construction sector skills demand – this aims to answer research question number six.

Chapter 7 - summarises the evidence from the preceding chapters that allows the primary research question to be answered on the basis of the secondary research questions.

In order to address the central research question the thesis initially examines why the UK construction sector will be critical for the Low-Carbon Transition (LCT) and the features of the sector that make it particularly susceptible to skills shortages. The thesis presents a theoretical explanation of the factors that drive skill formation and skills shortages. It then goes on to build on existing forecasting techniques to develop a series of scenarios that explore the features of the UK demand for construction and the roles of institutional settings and technical options that might influence the development of skills shortages and their impacts. Finally, the various demand scenarios are reconciled with skills supply scenarios and the potential for low-carbon construction skills shortages to arise is assessed.

This introductory chapter introduces the main arguments and new approaches used in the thesis to identify and examine the potential size and characteristics of any skills shortages that could impact on the transition to a low-carbon economy. Given the importance of achieving the LCT, any future skill shortages could be detrimental to the necessary trajectories to the 2050 low-carbon ambitions.

The thesis argues that construction sector is central to a successful transition because the sector will be responsible for building and installing most of the low-carbon electricity capacity and ensuring that both old and new buildings will be more energy efficient than in the past. Additionally, the construction sector will be responsible for delivering many other elements of the low-carbon infrastructure, including electrifying the railways and building new low-carbon manufacturing plants. Therefore, the current and potential future construction skills shortages in this sector are a cause for concern (Jagger et al., 2013). The thesis aims to examine the potential for disruptive construction sector skills shortages over the time span of the LCT and to identify the main drivers of any such shortages. Understanding low-carbon skills shortages enables the development of effective policy responses. The previous research has focused predominantly on high-level skills (Jacobsson and Karltorp, 2012; Autio and Webb, 2015) it has also tended to focus on immediate skills concerns rather than the longer term (Aldersgate Group, 2010). In contrast, this thesis concentrates on a broad range of skill levels within the construction sector over a longer period. Also, where earlier research has examined lower-level low-carbon skills (Cedefop, 2013), the scope has been broad and focused on the employment creation potential rather than the impact on capacity. Equally, where the focus has been on the construction sector, the forecasts have been too short to address the timeframe of the LCT. In addition, the underlying economic forecasts usually have not taken into account the business cycle. Since the construction sector, especially housing new-build, is heavily impacted by the regular boom and bust cycle (Kyland et al., 2012), not taking this into account limits the scope and plausibility of traditional forecasting methods.

Furthermore, most of the existing forecasts of UK construction activity cover periods of just two to three years (CPA, 2015; Hanley, 2014; Hewes & Associates, 2010) while the longest covers a period of fifteen years (CITB and Experian, 2015). Such (relatively) short-term forecasts, therefore, do not address the thirty years or more time horizon of the LCT (Committee on Climate Change (CCC), 2008). In summary, this means that to date there have been no long-term forecasts of the construction sector or the low-carbon skills required by the transition. Therefore, a major thesis objective is to fill the gap in long-term low-carbon construction skills forecasts.

Traditionally, models of future activity and skills demand in the construction sector are based on a forecast of sectoral output. The activity or output level of the construction sector mirrors the stage of the business cycle. However, the LCT in the UK involves a series of additional issues. Firstly, there are technical choices to be made, - for instance whether to adopt nuclear new-build or not -, secondly the necessary technical skills in the workforce have to be in place in order to deliver the low-carbon infrastructure.

As the LCT is a policy-driven objective, and must meet the legally binding targets of the Climate Change Act, this means that institutional factors and policy choices will remain central to achieving that ambition. This importance of institutions and policy in determining and directing the LCT means that they need to be taken into account when analysing skills and the LCT.

Over the longer term, innovation and policy change are likely to significantly influence the ease of low-carbon transitioning and, therefore, result in a different outcome than what would be predicted by economic factors alone. However, both technical change and policy change are difficult to forecast, as they are usually driven by both scientific and political developments. Any meaningful forecast for the skills requirements of the LCT needs to incorporate a series of scenarios covering technical and policy change.

Therefore, the third objective of this thesis is to produce indicative forecasts of the types of scenarios, technical change and policy choices that are likely to result in a skills shortage. It is accepted that the range of possible scenarios means that production of definitive numeric forecasts are unlikely to be possible. However, while the modelling process is not necessarily predictive, the use of this combination of forecasting and scenarios is intended to provide illustrative indications of the range, scope and scale of the different kinds of challenges the UK construction sector might face under certain conditions. The combination is, in turn, designed to inform the development of appropriate policies to mitigate any potential future skills shortages.

The rest of this introduction sets the scene for the thesis and reviews the basis for believing that there may be concerns regarding the skills required to support the LCT. The following sections provide this introduction:

- The importance of the LCT
- Why the construction sector is important for the transition
- The potential impact of skills shortages
- The theoretical problem
- The empirical problem
- The research questions
- Thesis structure.

1.3 The importance of the low-carbon transition and the skills required to achieve it

This section examines the need for a LCT and, as a consequence, the need to ensure that the UK has sufficient skills in place within the workforce to achieve it. The Intergovernmental Panel on Climate Change's latest report (IPCC, 2014) has confirmed that rapid climate change, with the warming of the land, sea and air, is largely attributable to human activities. Its impacts are likely to be disruptive, and all areas of society and the economy will be affected at global, national, regional and local levels (IPCC, 2012). This warming will lead to significant ice loss and sea level rises, as well as disruptions to other vital biological and social systems, agriculture and commerce, especially if emissions do not reduce and then plateau. The World Meteorological Organization has reported a decade of extreme weather, with record daily and annual CO2 levels (WMO, 2013). A UN Environment Programme report has shown that current emissions levels and abatement commitments mean that there is a widening emissions gap between current practice and the required pathway to stay below a two-degree temperature increase (UNEP, 2013). This widening gap means that the measures necessary to hit the target will now need to be more dramatic and more expensive than earlier efforts, especially since recent work suggests that the two degrees target for average temperature increases may be too optimistic, and that this may result in more significant negative impacts globally (Hansen et al., 2013).

This international evidence and other evidence reviewed by Lord Stern (2013) confirm the IPCC findings and again suggest that the problem may be more serious. Stern stated that: *"Such temperature changes, and other related climate effects, could transform the relationship between humans and the planet including where and how they could live"* (Stern, 2013: 839).

Therefore, it is essential, as the OCED Secretary General Angel Gurria has stated, that we achieve zero carbon emissions by 2050 (Gurria, 2013). To date, there have been numerous efforts to agree on international targets for the reduction of carbon emissions globally, most notably the common goals outlined in the Kyoto Protocol of 2005, and more recently the Paris Agreement led by the United Nations Framework Convention on Climate Change (UNFCCC, 2015). Since then national governments have introduced policies to implement more sustainable ways of producing and conserving energy in their countries. Importantly, the UK was the first country to introduce such legislation in the form of the Climate Change Act to reduce national emissions by 80% by 2050 (HM Government, 2008). To achieve the ambitious

UK decarbonization targets increased low-carbon skills will be required both at national and regional level.

November and December 2015 saw the 21st Conference of the Parties (COP 21) of the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris. This UN inspired meeting developed a consensus document agreed by all the 196 parties attending, which committed to a target of a maximum of 2^o Centigrade and, hopefully, 1.5^o rise in temperatures by achieving zero carbon emissions by the second half of the century. These ambitious targets will require a rapid global LCT.

1.4 Why the construction sector is important for the transition

There are various metrics that illustrate the importance of the construction sector for the LCT. The first – often cited by European Commission bodies – links buildings to some 40 percent of energy use and 36 percent of European carbon emissions (OJEU, 2010).

An estimate undertaken for the UK's Department for Business Innovation and Skills (BIS) suggests that the UK construction sector was responsible (either directly or indirectly) for 298.4 M tonnes of CO2 emissions in 2008 (BIS, 2010a). These emissions represented 36.6 percent of UK emissions (note that this figure includes indirect emissions from imports) (DEFRA, 2012). Given that the European Commission figure for building energy use does not include emissions from imports, these figures are of the same order of magnitude. Also, the sector will build and install most of the low-carbon infrastructure, especially the electrical generating equipment. Finally, the sector has relatively high levels of carbon intensity as many of its inputs, such as cement and steel, have high embedded carbon content (DEFRA, 2012).

Earlier work has noted the importance of the construction industry for the LCT and the potential problems. Sorrell, (2003) argued that the contract-based structure of the UK building industry means that it was poorly placed to address the challenges of the LCT. Sev (2009) uses a literature review to question the capacity of the sector for sustainable development. Sev argues that UK construction contractors need to put a greater emphasis on life-cycle design approaches and resource management to be sustainable. Both note the fragmented structure of the construction sector as the source of many problems. However, despite some suggestions regarding how the sector can become more sustainable (Adetunji et al., 2003), there has not been much attention paid to the scale of the effort required (PWC, 2010). While some of the earlier literature concentrated on characterising the skill requirements of the LCT (Pro-Enviro, 2008; Aldersgate Group, 2010), this was mainly from the policy perspective. To date, these have been no attempts to forecast the numbers of the workforce required to achieve the transition or to identify any potential areas of skills shortage.

Chapter 2 of the thesis contains more details of these arguments and also explores why the structure of the construction sector potentially poses a challenge for the LCT. As such, the objective of Chapter 2 is to place the UK construction sector, with its flaws, at the centre of the efforts to achieve the LCT.

1.5 The potential impact of skills shortages

This thesis argues that skills shortages represent the main challenge the construction sector faces regarding achieving the goals of the LCT. Previous research has demonstrated that skills shortages relate to a range of negative consequences including the need for rework (Love and Li, 2000), cost overruns (Sovacool et al., 2014a) and sub-standard results (Barber et al., 2000). Equally, earlier research shows that different electricity-generating infrastructure types have different propensities to cost overruns due to skill shortages. Nuclear power stations are most likely to cause cost overruns and small scale solar the least likely (Sovacool et al., 2014b). Given the importance of achieving the LCT, the fourth objective of this thesis is to identify the scenarios that minimise skills shortages and any associated risks to the transition.

However, before these tasks can be undertaken the commonly used definitions of skills shortages and the methods used to predict them need to be examined.

1.5.1 Existing definitions and forecasts of skill shortages

There is no common definition of skills or skills shortages (Sala, 2011). One definition of a skill shortage results from employers reporting difficulties recruiting or retaining the skills they require (Greig et al., 2008). This definition is used widely in policy reports and surveys of employers. However, there are limitations to this when applied to the LCT. Although useful for describing the current and short term situation, this approach is less useful for predicting future skills shortages in the longer term, which is necessary when forecasting skills requirements for the LCT in the years between now and 2050.

The more conventional method of forecasting skills shortages is to calculate the likely demand for skills and the probable supply, with any negative mismatch between skills needs and supply representing a skills shortage (Metcalf, 1995). As this approach uses a mismatch between supply and demand, it is also sometimes referred to as a skills mismatch method.

The demand forecast also has problems when applied to the LCT. It is based on an economic forecast of the whole economy, broken down by sector. The demand forecast is used to produce a sectoral headcount forecast. This, in turn, is converted into an occupational forecast, based on the current occupational breakdown, by sector, and taking into account the changing sector level occupational trends over the previous ten years (Wilson et al., 2004). This approach does not specifically identify any additional impact of technical changes on skills requirements since the historic occupational change is considered to reflect technical and institutional change occurring at the sectoral level and is, therefore, simply rolled forward. In effect, the historic occupational change provides a proxy for the impact of technical and institutional change. This lack of differentiation between occupational change, technical change and policy change may not be a problem in the short-term, but is problematic over the longer-term, which is necessary for the LCT. In the specific context of modelling the forecast demand for skills in the construction sector over the period of the LCT, this traditional method is inadequate. This is because technical change is influenced by both global and national policy interventions to drive the transition and cannot simply be rolled forward.

In summary, therefore, it can be seen that existing methods of forecasting skill shortages have three basic disadvantages for looking at the LCT:

a) The economic forecasts underlying the skills shortage forecasts have shorter time horizons compared to the length of the LCT;
b) The economic forecasts often have problems addressing changes in the business cycle;
c) Do not distinguish between technical and institutional change as additional drivers of skills shortages.

Furthermore, the Transition will be critically dependent on the efforts of the UK construction sector, which will be responsible for building the new energy infrastructure, as well as low-carbon buildings and the retrofitting of existing structures. Therefore, in addition to the fact that the construction forecasts need to be longer and run to 2050 and beyond, the disadvantages of the traditional approach become a particular problem for the LCT, for the following reasons: The forecast needs to reflect the importance of the business cycle for the dynamics of the construction sector. A recent example of this is that the construction sector in the UK lost almost a third of its employees following the economic crash of 2007-2008. Such a drop in the construction workforce could seriously impede the transition.

The UK construction sector skills have been subject to institutional changes, with recent changes to the funding of training and a growing emphasis on apprenticeships. It is necessary to distinguish the impact of these changes from the demands related to the technical changes associated with low-carbon energy options, to develop appropriate policy responses.

These problems with the traditional approaches outlined above demonstrate that a new theoretical understanding and forecasting approach specific to address the needs of the LCT is required. The next section outlines the theoretical problems before moving on to provide a theoretical model that addresses these problems.

1.6 The theoretical problem

In general, skills shortages are poorly understood and poorly measured (Green and Ashton, 1992), partially, as a result of the dominant neoclassical explanations of skills shortages (Cappelli, 2014) and the existing measures of skills shortages outlined in Section 3.2.2. In particular, there is no adequate theory of the drivers of construction skills shortages. This is especially problematic in the context of the LCT and within the construction sector, which is central to delivering the necessary infrastructure to address climate change. Traditionally, models of future activity and skills demand in the construction sector are based on a sectoral economic forecast. The problem is that, in addition to economic drivers, and as stated earlier (1.1, 1.2) the LCT involves a series of technical choices, for instance whether to adopt nuclear new-build or not. Different technologies lead to different types of energy supply systems, with different social and economic consequences. Likewise, the larger construction sites have different labour relations and different skill demands. Equally, the relatively short horizons of the traditional forecasting models do not cope well with the longer (30 years or more) timelines of the LCT.

In addition to changes in technology, government policy interventions and the activities of institutions in terms of providing training, qualifications can cause further complications. These factors are more difficult to forecast because they are usually politically-driven, and both government policies and governments can change. Therefore, over a longer timescale, policy interventions can have significant impacts on the skills system and patterns of demand. Often the policy interventions are not specifically aimed at skills but impact skills indirectly as a result of decisions made in other policy areas. For instance, the repeated rapid reductions in the UK's Feed-in-Tariff support for solar power led to repeated collapses in activity (Muhammad-Sukk et al., 2013).

These collapses in UK renewable activity, in turn, reduced the interest amongst potential renewable heat installers to obtain the necessary qualifications to benefit from the Renewable Heat Incentive. The impact of policy interventions is clearly important when it comes to meeting the long-term skills requirements to achieve the LCT. This view of skills, and the complex role of institutions and technical change, has led to a further thesis objective which is to develop a theoretical understanding of skills and skills shortages that incorporates technical change and institutional change.

This thesis builds on previous approaches to analysis and predicting of skills shortages by applying evolutionary economics to address identified shortcomings in skills forecasting. In particular, the work adopts the concept of 'coevolution', to further develop ways of conceptualising skills and the causes of skills shortages. Co-evolution borrows concepts from biology, but has been applied especially to ecological economics (Kallis, 2007). A generic definition of coevolution states that: "Two systems coevolve when they both evolve … and they have a causal influence on each other's evolution" (Kallis and Norgaard, 2010: 690). Critically, the component systems of a co-evolving system need to have the ability to evolve as a result of variation, selection and inheritance (Norgaard, 1994). Without the variation, selection and inheritance, the systems could be considered to be co-dynamic (Kallis, 2007). Usually, within ecological economics, the idea of co-evolution has linked biological and social systems (Gual and Norgaard, 2010), although, Nelson and Winter (1982) used the concept as the basis for evolutionary economics. Equally, Thelen (2004) uses an evolutionary approach to examine how skills and institutions co-evolve. Foxon (2011) produced a framework with five co-evolving components that included technologies and institutions to assist with understanding the LCT.

The concept of ‘inertia’ within such a coevolving system of skills, institutions and technical change provides a way of explaining skills shortages. Inertia occurs when one sub-system of a co-evolving system does not successfully adapt to changes in the other sub-systems. Evolution does not have a teleological tendency towards a successful steady state. The necessity for variation and selection implicitly implies the possibility of unsuccessful variation. This, in turn, means that one or more component system of a co-evolving system can lose contact with the other components. Complex systems will already have a tendency to inertia, as each system will contain within itself mechanisms to stabilise and maintain the status-quo (Hannan and Freeman, 1984).

However, skills inertia is difficult to measure and is usually only apparent as a result of its impacts, mainly in the form of skills shortages. A particular cause of skills institutions lagging behind is the privileged role given to employers within the current UK skills systems (Payne, 2008a). This makes it difficult for the institutions to anticipate or mould future demand. A coevolving system allows, and requires complex multi-dimensional interactions which need to be reflected in patterns of governance and policy formation.

The next section outlines the model of skill formation and skills shortages developed for this thesis and detailed in Chapter 3 of this thesis.

1.7 Theoretical approach

The third chapter of the thesis aims to provide the theoretical underpinnings of the thesis. The central task of this work was to develop a model which could be used as a tool to identify any likely causes of skills shortages, the scale of any potential skill shortages and the extent to which these would be likely to disrupt the transition to a low-carbon economy. Therefore, a theoretical model was developed that could be used to analyse and identify skills shortages and their drivers, based on evolutionary economics. The model builds on existing theoretical approaches to identifying skills shortages by additionally analysing the impacts of technical and policy changes on shortages. However, before introducing the new model, the next section outlines the existing understanding of skill shortages. Additionally, the approach builds on Foxon's co-evolving understanding of the LCT (Foxon, 2011). This existing skills models and the co-evolving model are set out in the following sections.

1.7.1 The co-evolutionary model

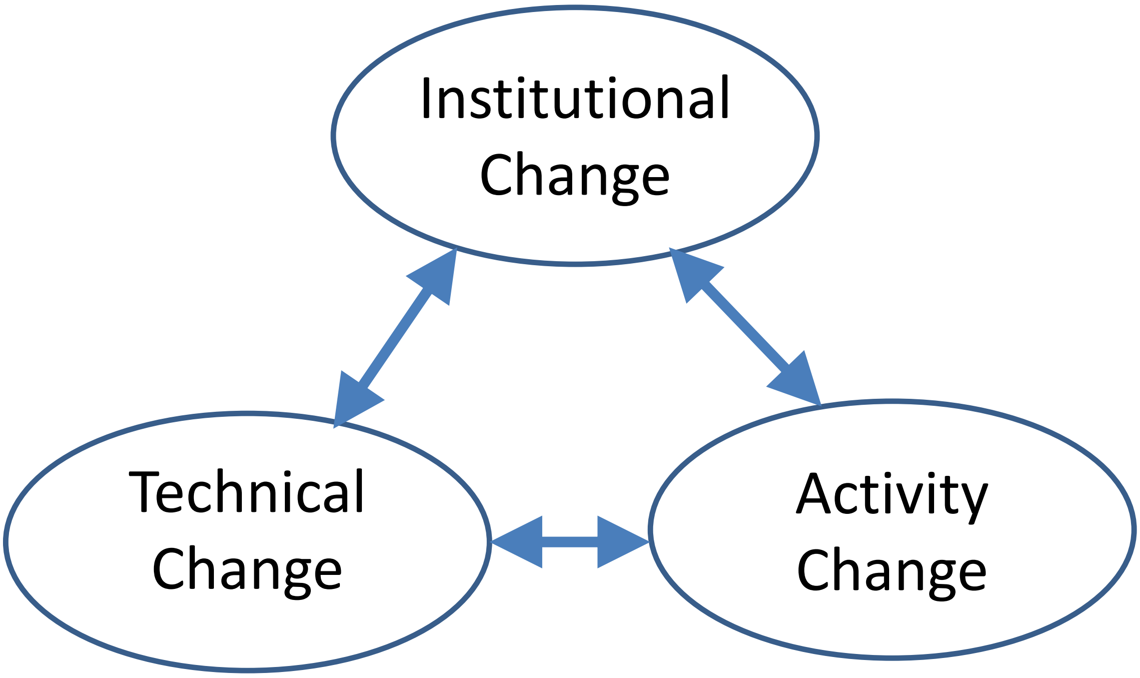
Given the preceding problems with the traditional approach to forecasting skill demands, this thesis utilises an original approach to understanding the drivers of skills shortages, based on evolutionary economics. The new model proposed argues that no single factor, such as technical change, determines skill demand. It proposes that three co-evolving systems drive construction skills demand. These three co-evolving systems are:

- Economic activity change
- Technical change, and
- Institutional or policy change.

This thesis postulates that imbalances between the various systems can lead to skills shortages. An analogy of the new forecasting model would be to view it as a three-legged stool, each leg representing one of the drivers of skill shortages. Thus, if inertia causes one leg to fall behind the other drivers, it causes instability and skills shortages emerge.

These are broad concepts and the interactions within and between each driver are complex. The complexity means that it is difficult to forecast and ensure the inclusion of all the features. The thesis aims to explore critical features of each driver in order to gain a better understanding of the possible causes of, and possible remedies for, skills shortages impacting on the LCT

Figure 1.1: The Co-Evolving Skills Model



Source: Chapter 3 of the thesis

By breaking down the three different potential causes of skills shortages, the co-evolving model allows a more detailed, longer-term forecast of them. This model is in contrast to traditional methods which make projections only by past occupational trends within the sector. This new model is particularly advantageous for analysing the LCT as it allows the explicit inclusion of technical change and technology options and their impacts on skills. However, the new model does not produce a simple single figure for future skill demand. The technical and policy options need to be incorporated as a series of options.

While valid for forecasting over the shorter term, traditional methods become less useful when forecasting over the longer term necessary for the transition. The more traditional models of identifying skills shortages use data obtained from employers in the sector reporting recruitment or retention problems and, to some extent, are informed by the national data available on salaries within sectors. Moreover, traditional skills shortage forecasting models are based on short-term demand change, while bundling up institutional and technical change together into a single component, based on historical occupational changes identified in the sector. The coevolutionary approach adopted here has been specifically designed to allow the impact of technical and institutional changes, as well policy interventions to be examined separately in order to more accurately predict longer term trends and any potential skills shortages to provide more detailed forecasts over the longer timescale of the transition. The forecasts generated will, hopefully, benefit employees, and inform employers, institutions and the UK government and enable them to put in place appropriate policies, qualifications and training programmes to provide sufficient numbers of skilled workers in the construction industry to achieve smooth progress and implementation of low-carbon infrastructures.

The new co-evolving model for forecasting skills could be applied more generally to other sectors. In particular, the negative impact of sub-systems within a coevolving system lagging behind has a more general application to understanding the dynamics of such systems. Equally, the idea of coevolution is generally used to describe retrospectively the development of systems. Here, in contrast, it is additionally used to provide the basis for empirically based numerical forecasts. Therefore, in this thesis it is used to forecast the potential for skills shortages in the UK construction sector in the context of delivering the LCT. The thesis examines each co-evolving sub-system separately and then holistically. The model may appear simple, but by making the interrelationships between economic activity levels, technical change and institutional change explicit the model allows exploration of the complexity surrounding skills.

1.8 The empirical problem

The full trajectory of the LCT remains uncertain (Baker and Shittu, 2008) even if the Climate Change Act (HM Government, 2008) defines the ambition regarding reductions. The uncertainty means that it is difficult to predict the exact employment and skills implications of the LCT (Kannan, 2009).

As a result, a series of scenarios will be used to explore the consequences of a range of technical and policy options that could be adopted to achieve the carbon reduction targets for the UK. These scenarios will incorporate as much of the quantitative evidence that is currently available to provide as accurate as possible estimates of construction skill requirements.

1.8.1 The use of scenarios

A common way of dealing with the inevitable uncertainty of long-term forecasting is the use of scenarios (Van der Heijden, 2005). Demographic driven GDP scenarios underlying a series of socioeconomic pathways (O'Neill et al., 2015) have a similar purpose to these scenarios, in that they are designed to make potential problems for the LCT clearer. However, the GDP scenarios underlying the socio-economic pathways are based on a wide range of long-term trends, and no effort was made to identify and project business and other cycles (Leimbach et al., 2015). The absence of business cycles is not a problem for the socio-economic pathways. However, given the impact of the business cycle on the construction sector and, in particular, the construction workforce, with construction employment dropping by 30 percent from the pre-crisis peak in 2007 to 2010 in the UK, the business cycle needs to be included in any long term forecast of construction. Therefore, to generate an accurate forecast for construction skills over the period of the LCT, the core economic forecast needs to include business cycles and then further scenarios build on this core forecast. Therefore, Chapter 4 provides a core economic forecast of UK construction sector activity until 2050, using Multi-Channel Spectral Singular Analysis. Supplementing this core forecast is are forecasts and anlsyses for a series of scenarios covering different technical options and technical change in Chapter 5. Chapter 6 follows with a series of institutional change scenarios. The final Chapter 7 draws together the scenarios from Chapters 4 to 6 and suggests appropriate policy responses.

1.8.2 The various scenarios

Following the theoretical chapter, there are three chapters exploring empirical aspects of each of the three sub-systems of the co-evolving model. The first forecasts core levels of construction activity, using a technique that has only recently been used with economic data Multichannel Singular Spectral Analysis (MSSA). MSSA allows data to be forecast over longer than normal periods taking account of any existing cyclic patterns such as business cycles. More importantly, in terms of the evolutionary economic approach taken by the thesis, these forecasts are model free and are based on the interactions of key variables. The forecast of GDP to 2064 is based on co-evolving forecasts of investments and productivity, while incorporating information from projections of working-age population and tertiary level attainment. The modelling method incorporates information from the trends, cyclic behaviours and interactions between the various variables included in the forecast. The economic forecast is then used to provide the basis for a forecast of construction activity, which becomes the core economic led construction activity forecast. This core construction activity forecast is then used as the basis of technical change scenarios in Chapter 5 and institutional change scenarios in Chapter 6.

Using DECC 2050 Pathways, a series of possible technical mixes that are bundled together to achieve the required carbon emission reductions provide the basis for analysis of a range of technical change scenarios in the thesis. These will all use the number of construction employees required to achieve them as a common basis for comparing the impact of the pathways. Additionally, the skill profiles of construction subsectors, combined with profiling the technologies, will be used to provide detailed skill profiles of the pathways. These pathways and their analysis form the basis of Chapter 5.

A range of policy and institutional options provide the basis for a further set of scenarios in Chapter 6. These explore the possible impact of potential policy decisions that can have an impact on the demand for construction skills. These include a programme of mass zero-carbon house building, to address housing shortages, and the concentration of infrastructure investment to the downturns of the business cycles. Additionally, the pattern of construction skills governance and its adequacy in the face to the challenges posed by the LCT are examined.

The final chapter draws together the information from the preceding chapters and provides a series of policy conclusions based on the analysis.

2 – Construction and Risks

2.1 Introduction

This chapter aims to justify the focus on the construction sector within the thesis as one of the key factors to achieve the success of the low-carbon transition. It examines the features of the construction sector that could produce skill shortages that could potentially pose a risk to the low-carbon transition. As such, this chapter addresses the research question:

> *"What features of the construction sector pose a problem for the low-carbon transition in the UK?"*

The chapter initially defines the low-carbon transition (LCT) and the role of skills leading to a definition of low-carbon skills. The definition of low-carbon skills adopted by focusing on carbon reduction, provides the basis for placing the construction sector at the forefront of the LCT. The chapter then examines the features of the UK construction sector that make its contribution potentially problematic. The thesis argues that, at the core, the fragmented structure of the sector has negative impacts on skills, training, productivity and innovation within construction. These potential negative impacts could, in turn, mean that the ambitions of the LCT are not met. Given this risk to the LCT the construction sector, and the demands that will be put upon it, are worthy of detailed examination. The structure of the sector, is analysed by examining the size structure of the industry on an annual basis. This shows the size of establishments and identifies the fragmentation of the sector into small companies. This data is then combined with employment and training data from the Labour Force Survey and Construction Activity data to produce a specifically constructed dataset. The dataset and is then used to argue that the consequences of fragmentation make the sector particularly vulnerable to the business cycle and changes in technology and policy.

2.2 Why the construction sector

The section aims to demonstrate the importance of the construction sector when considering low-carbon skills. This process starts with a definition of skills and then low-carbon skills. The definition of low-carbon skills focuses on the capacity to reduce emissions and implement the low-carbon transition. This provides a starting point for understanding the critical role of the construction sector. The next section examines the role of the construction sector in reducing emissions and, finally, its role in providing the necessary low-carbon infrastructure for the transition. None of these aspects alone suggests that the construction sector will be critical. However, the combination indicates the critical role the sector is likely to play and underlines the importance of identifying the potential for disruptive skills shortages. The sector will not be solely responsible for reducing emissions or represent the focus for of all low-carbon investments. However, the contribution of the sector to emission reductions will be much greater than its proportion of total employment. Equally, it is the sector where there are existing concerns about skills (Sorrell, 2003), so it is more likely to be the locus of concerns about low-carbon skills. The sector is also particularly dependent on intermediate level skills, and it is at this level that there are existing concerns about the UK's skill provision (Leitch, 2005).

2.2.1 Defining skills and the low-carbon transition

A thesis examining 'The skills requirements of the low-carbon transition' needs to understand the meaning of both 'skills' and the 'low-carbon transition'. This subsection aims to define skills and the next subsection to define the low-carbon transition.

The term 'skills' has many meanings, and the definition used in this thesis is a broad interpretation of the concept, as outlined in this quote:

> *"A skill can be defined as an ability or proficiency at a task that is normally acquired through education, training and/or experience. It can at times be synonymous with the*

related concepts of competence, expertise, knowledge and human capital." (Tether et al., 2005: 5)

The advantage of this definition is that it takes the understanding of skills beyond the simple one of actual skills and competencies. However, the definition also encompasses the ability to perform specific tasks. Chapter 3 further explores this definition and its implications. Usefully, this concept of skills can be applied to individuals, enterprises, sectors and countries. In the following sections it is applied to sectors, based on the understanding that the capability of a sector is dependent on the training and competencies of the individuals working in the sector.

In another, 'skills ecosystem' approach the capability of a sector also depends on the way in which the individual and corporate capabilities are mobilised and directed (Windsor and Alcorso, 2008). The concept of skills ecosystems emphases that simply providing training, without examining how skills are utilised does not adequately explain the impact of skills on productivity or output (Hall and Lansbury, 2006). This view of skills as embedded in sectors and the ways that management use skilled labour, suggests that skill shortages are not simply a result of training deficits but can also be due to customs and practices as well as deficits in management capability (Payne, 2012).

The concept of skills ecosystem has its roots in an analysis of the perceived failure of skills training in the UK by Finegold and Soskice (1988) that argued that the UK was stuck in a low-skilled equilibrium. They argued that institutions and business strategies perpetuate a low-skill, low value-added equilibria (Finegold, 1999). This idea then led to the idea that skills and their utilisation were dependent on a complex eco-system of "political-economic" institutions that help maintain the status quo (Anderson, 2010). This relationship between skills and surrounding institutions provides part of the guiding theory for this thesis that is developed in Chapter 3.

This view of skills highlights the need for the thesis to address a wider range of drivers of skills shortages than the more common idea of skills shortages arising simply from market failure. In particular, the thesis needs to examine the governance of skills and competencies, as well as how training is funded and encouraged. Additionally, technical change, and how it is addressed in policy terms, potentially has a role in creating skills shortages.

2.2.2 Defining the low-carbon transition

The existing literature describing the low-carbon transition is extensive, and this is not an attempt to review this literature. However, some the key features of the transition are outlined here. A longer review of the literature on the low-carbon transition is contained in Chapter 3.

The term ‘low-carbon transition’ entered the UK policy debate with the 2009 National Strategy for Climate and Energy (HM Government, 2009a). This Government document provided a strategy to respond to the 2008 Climate Change Act (HM Government, 2008). The term rapidly gained policy and academic usage, covering the complex set of processes that are involved moving from our current economy to a low-carbon economy. The low-carbon transition involves the reduction of carbon emissions to virtually zero (Foxon, 2013). In the UK, these targets are to be achieved mainly by ensuring that electricity generation is zero-carbon and that many uses of fossil fuels, such as vehicles and heating, are replaced by electricity (Ekins et al., 2013). It also involves massive investment in the infrastructure to ensure cleaner and sustainable methods of energy production and use, such as the building of wind farms, new nuclear plants and the installation of solar panels.

At the same time, the LCT envisages massive improvements to energy efficiency, mainly through retro-fitting existing builds and by making new build much more energy efficient (Deakin et al., 2012). Improvements to efficiency also involve changing industrial processes and equipment, adjusting farming and trading practices, as well as changes to the behaviours of individuals. Such a strategy is seen as essential to avoid catastrophic climate change (Stern, 2015).

2.2.3 Defining low-carbon skills

A simple definition of skills involves the ability to undertake successfully the tasks required of individuals, companies sectors or countries, using knowledge acquired through education or training (Bryson, 2015). This implies that low-carbon skills are the abilities required to implement the LCT.

A definition of green and low-carbon jobs is an essential starting point for an analysis of skills and the LCT. Unfortunately, no standard or common definition exists and those that do are often contradictory. A recent report by the International Labour Organisation (ILO) concluded that: "While there are several definitions of "green" suggested by various individuals and organizations, no commonly accepted definition exists" (IILS, 2011). The ILO also argue that any definition adopted should be appropriate to the intended task the definition will be put to. They concluded:

> *"An appropriate definition of a "green economy" or of "green jobs" is one that is useful for a previously determined purpose. Some reviewed definitions focus on the purpose of output or work when defining "green", i.e. whether the produced goods and services can be used to "green" the economy. Others focus on environmental impacts of output and work, i.e. whether the production or consumption damages the environment or is unsustainable ("ecological footprint")." (IILS, 2011: 1)*

Since the thesis covers low-carbon skills, it is important that any new definition proposed should link to either existing occupational or sectoral definition, as these are the accepted basis of analysing skills formation and governance. In preference, any definition adopted in the thesis should be defined in terms of existing occupational classifications, as this makes it easier to make a link to qualifications, as well as training provision.

However, the lack of a consistent definition of low-carbon causes problems, as an earlier study of low-carbon jobs noted:

> *"Moving to a Low Carbon and Resource Efficient Economy will require a fundamental transition in behaviour and application of skills and knowledge. Understanding and awareness is a crucial issue. The interchangeable use of terms such as sustainable development, green, eco, environmental is causing confusion. Each term means different things to different people and there is a lack of clarity in the economy as a whole as to the characteristics of a LCREE and consequently what the skill requirements may be." (Pro Enviro, 2008: page 5)*

In order to address this ambiguity, Pro Enviro proposed a wide-ranging definition of what they term Low Carbon and Resource Efficient Economy (LCREE) jobs. These are jobs within the low-carbon economy, which aim to:

> *"…integrate all aspects of the economy, manufacturing, agriculture, transportation and power-generation etc. around technologies that produce energy and materials with minimal Greenhouse Gas emission; and thus, around populations, buildings, machines and devices which use those energies and materials efficiently, and, dispose of or recycle its wastes." (Pro Enviro, 2008: page 13)*

Pro Enviro's definition is deliberately wide in order to include all economic activities and occupations within a low-carbon context. This broad definition has the advantage of encompassing virtually all occupations necessary to operate in a low-carbon economy, as well as including the more obvious installers and operators of low-carbon technologies. Such a broad definition is important in terms of arguing that a low-carbon economy will be very different from the current economy. As such, all occupations will have to include some changes to adapt to the low-carbon economy. However, whilst useful in providing a generic definition of low-carbon skills, it does not assist in terms of identifying which occupations and skills will be critical for the low-carbon transition. This is discussed in the next section which reviews the current approaches to identifying and forecasting low-carbon skills and an occupational level.

2.2.4 Review of existing approaches to low-carbon skills

Most existing approaches to defining low-carbon skills use either a bottom-up or top-down approach. The top-down approach usually starts with a model-based forecast of low-carbon developments and then breaks this down to produce details of how this impacts on specific occupations. This has the benefit of a consistent overall picture, but produces very little disaggregated information (BIS, 2015). This means that data at the level of occupations, or associated skills, tends not to be produced by this approach. Therefore, little information of use for skills policy makers about shortage occupations, or for deciding which training courses to support, is provided. Although, this approach is used to produce politically useful estimates on the number of low-carbon jobs created by the transition (UNEP/ILO/IOE/ITUC, 2009).

In contrast, the bottom-up approach involves working from example 'green' or 'low-carbon' occupations, or sub-sectors, and then aggregating the results to attempt an overall picture. The occupations are often selected on an ad-hoc basis. Therefore, the overall picture generated by this approach is unlikely to be accurate. Often, to be clear about the low-carbon status of the selected occupations, the definitions used do not relate to existing occupational or sectoral classifications. However, the bottom-up approach is useful as it generally produces detailed information for the selected occupations (Bureau of Labor Statistics, 2010a). However, an important consideration when evaluating these existing definitions is that often both these approaches to understanding low-carbon skills are difficult to replicate, especially internationally, as they require access to detailed national data or expensive surveys (Bureau of Labor Statistics, 2010b).

To help address some of these existing problems to understanding low-carbon skills, the thesis will utilise a combination of both top-down and bottom-up approaches. This combined approach focuses on the occupations, and hence skills, that will provide the low-carbon energy systems and energy efficiency measures needed as part of the low-carbon transition. Many of the existing definitions outlined above, especially those defining ‘green’ occupations or ‘green’ sectors, essentially are looking at an end state when we have a green economy. However, in terms of the low-carbon transition, the very term is looking at the change from a high-carbon economy to a low-carbon economy. This means that the focus of interest is on which occupations or sectors will be most influential in that transformation rather than any end state. Since the thesis aims to examine the skill requirements of the low-carbon transition an approach reflecting the process of change to a low-carbon future is adopted in the following subsection. The next sections outline why construction occupations meet the requirements of this approach and will be responsible for the bulk of the reductions in carbon emissions and responsible for much of the required low-carbon investments.

2.2.5 Emissions reduction

As previously mentioned in the introduction, one of the key reasons this thesis concentrates on the construction sector is because there is a commonly cited figure that buildings are responsible for 40 percent of energy use in Europe (OJEU, 2010). The Department for Business Innovation and Skills estimated that the construction sector, either directly or indirectly, influenced 298.4 M tonnes of UK CO2 emissions in 2008 (BIS, 2010a). This level of emissions represented 36.6 per cent of all emissions that the UK was responsible for in 2008, if imports are taken into account (DEFRA, 2012). However, as Table 2.1 shows the bulk of these emissions are due to in-use emissions resulting from heating, lighting and other energy use. The BIS figure for emissions is measured on a different basis than the European Commission’s figure of 40 percent, but still represents a significant and relatively concentrated figure.

Table 2.1: Amount of UK CO2 emissions that the construction sector can influence, 2008

	MtCO2	Percentage of total
Design	1.3	0.5%
Manufacture	45.2	15%
Distribution	2.8	1%
Operations on-site	2.6	1%
In Use	246.4	83%
Refurbishment or Demolition	1.3	0.4%
Total	298.4	100%

Source: BIS (2010) 'Estimating the amount of CO2 emissions that the construction sector can influence', p. 4

By constructing zero-carbon homes, and retrofitting energy efficiency measures to existing buildings, the construction sector will be responsible for addressing the emissions due to building use. The construction sector will also be responsible for building the new low-carbon energy infrastructure. The next subsection addresses this issue.

2.2.6 Low-carbon capital investment

The construction sector will also be responsible for building the new low-carbon generating capacity. The increase in activity derived from constructing and installing these low-carbon technologies is partly dependent upon the mix of technologies that are adopted by the UK government. The estimated expenditures for low-carbon building work and low-carbon electricity infrastructure are in the region of £28 billion per annum in 2015, rising to between £54 billion to £67 billion per annum by 2050. These large sums need to be put into the context of the £135 billion total output for the construction sector for 2014.

Table 2.2 details the estimated costs for broad categories under a 'higher nuclear' scenario and a 'higher renewables' scenario from DECC's 2050 Pathways. The use of scenarios by DECC reflects the considerable uncertainty about the technologies that will be needed and the sequence of events in the low-carbon transition (Hughes et al., 2013). These Pathway costs are point costs and are subject to wide margins of error and do not provide a direct link to construction activity or construction employment. However, it is clear that regardless of the actual scenario adopted, the UK construction sector will be responsible for building large amounts of required low-carbon infrastructure.

Table 2.2: Scale of low-carbon capital investment under different scenarios (£ million)

	Higher Nuclear				Higher Renewables			
	2015		2050		2015		2050	
	(£ million)	(%)	(£ million)	(%)	(£ million)	(%)	(£ million)	(%)
Electricity	5,334	5.8	10,308	7.8	7,159	7.5	18,949	12.9
Building	21,491	23.3	43,802	32.9	21,894	23.1	48,171	32.8
Transport	60,235	65.3	72,015	54.2	60,235	63.5	72,015	49.1
Other	5,175	5.6	6,835	5.1	5,588	5.9	7,638	5.2
Total	92,235	100.0	132,960	100.0	94,876	100.0	146,773	100.0

Source: DECC 2050 Pathways

Chapter 4 provides a more detailed linkage between expenditure and construction activity, as construction costs represent variable proportions of the capital costs of different low-carbon technologies. However, using a direct link between expenditure and construction activity the importance of the construction sector for the transition can be derived. Using the linkage shows that, the cost of replacement of the electricity generating capacity will more than double over the period in both scenarios. While the per annum cost of capital investment in Buildings is also forecast to more than double between 2015 and 2050.

Therefore, the construction sector, will be responsible for the bulk of the electricity and building capital expenditure. Using a crude direct allocation of these expenditures to construction, under the higher nuclear scenario, construction's contribution increases from 29.1 in 2015 percent to 40.7 percent in 2050. Under the higher renewables scenario, this increase is from 30.6 percent to 45.7 percent. As already mentioned Chapters 4, 5 and 6 provide a more detailed analysis of the contribution of the construction sector and the skills implications. However, this analysis is sufficient to illustrate the importance, and growing importance, of the construction sector for the low-carbon transition. Therefore, the next section characterises the UK construction sector and its ability to rise to the LCT challenge.

2.3 The UK construction sector

The intention is to focus this section on the UK construction sector and how it is likely to be the main enabler of carbon reductions by other sectors. However, the problem is that there is concern that the sector may not be capable of what is being asked of it (Sorrell, 2003). This section explores and documents the features of the sector that underlie these concerns. These are:

- The structure of the sector
- The skills of the sector
- The productivity of the sector
- The sector's capacity for innovation, and
- The provision of training by the sector.

2.3.1 Structure of the construction sector

The UK’s construction sector structure is notorious for relying on many small and micro businesses (Forde et al., 2009). To illustrate this Table 2.3 provides details of the numbers of business enterprises and the number of local units, by size, for the construction sector compared to the whole economy. Local-units are the smallest unit that has a separate VAT or PAYE code, while enterprises can incorporate more than one local-unit.

Table 2.3: Business entities by size of employment in construction and all sectors, 2014

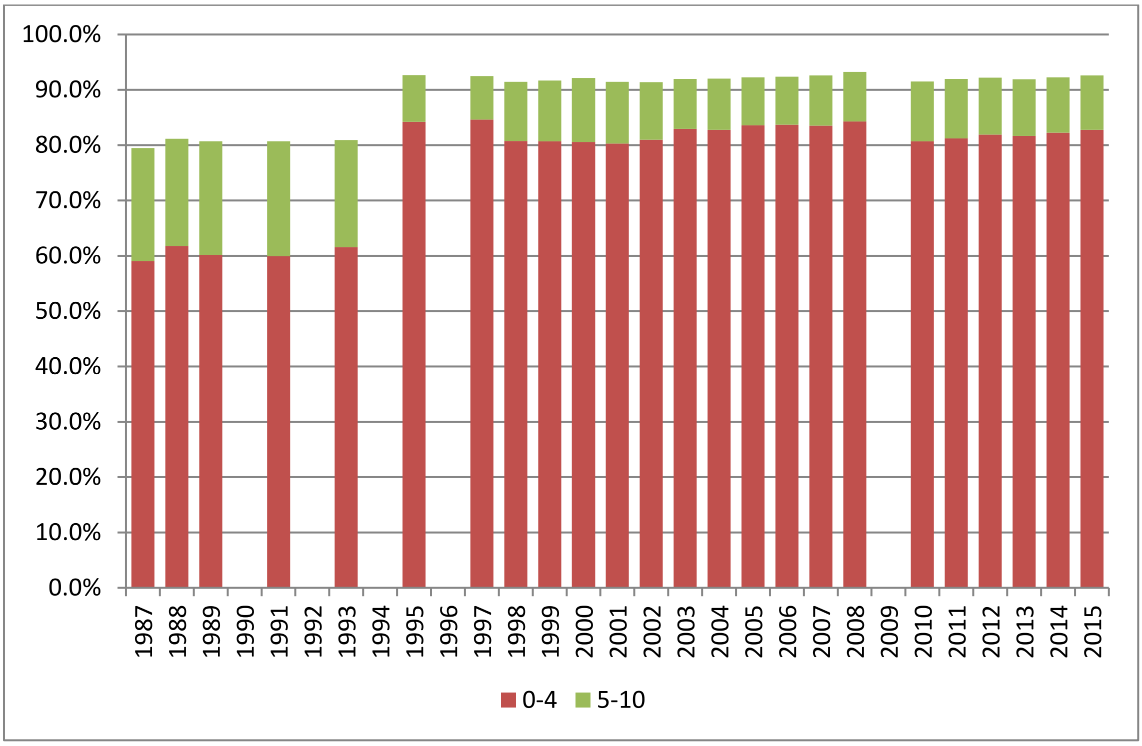
	Enterprises				Local-units			
	Construction		All Enterprises		Construction		All Local units	
	(N)	(%)	(N)	(%)	(N)	(%)	(N)	(%)
0 to 4	239,130	84.1	1,869,125	76.3	243,255	82.8	2,018,940	69.4
5 to 9	27,150	9.5	304,230	12.4	28,900	9.8	411,580	14.2
10 to 19	11,315	4.0	149,465	6.1	12,645	4.3	235,170	8.1
20 to 49	4,745	1.7	78,305	3.2	5,950	2.0	151,255	5.2
50 to 249	1,805	0.6	38,940	1.6	2,820	1.0	78,685	2.7
Large (250+)	285	0.1	9,350	0.4	255	0.1	11,935	0.4
Total	284,430	100.0	2,449,415	100.0	293,820	100.0	2,907,560	100.0

Source: ONS and Inter Departmental Business Register via NOMIS

The table shows that 84 percent of Construction Enterprises consisted of 0 to 4 employees compared with 76.3 percent of All Enterprises. By comparison, the 2.4 percent of Construction enterprises had more than 20 employees and 5.2 percent of All Enterprises had the same number of employees. The difference between construction local-units and local-units in all sectors are more extreme than the difference at the enterprise level. This reliance on small units has implications for training and innovation, as dealt with later.

Self-employment, as suggested by the average size of local units, is a critical feature of the construction sector. Figure 2.1 illustrates a time series constructed from four broadly comparable sources. The chart shows the percentage of the construction places with zero to four employees and five to ten employees.

Figure 2.1: Percentage of construction workplaces with 0-4 and 5-10 employees



Source: 2010-2015 Business Register and Employment Survey; 1998-2008 Annual Business Inquiry – workplace analysis; 1990-1997 Annual Employment Survey – workplace analysis; 1987-1989 Census of Employment – Workplace analysis – All from ONS via NOMIS

There are minor differences in the Standard Industrial Classification (SIC) used, but the construction sector has remained relatively consistent through a series of SIC changes. Similarly, there have been some changes in the collection methods and scope of the surveys. However, within each source, the methods and classifications have been consistent. Therefore, the relatively dramatic increase in small businesses between 1993 and 1995 is interesting, as this is in the middle of a single source, the Annual Employment Survey – workplace analysis. It is, therefore, not a result of definitional change. Equally, it is difficult to distinguish any significant changes as a result of the business cycle. This lack of evidence indicates that the shift in 1993 to 1995 was probably a result of changes in the tax system that encouraged self-employment (Briscoe et al., 2000). Similar, growth of construction self-employment as the result of tax systems were found in Australia (Buchanan and Allan, 2000). However, taxation is not the only pressure driving fragmentation. The widespread use of subcontractors within the sector also creates fragmentation, (Winch, 1998). Arguably, the structure of the construction sector is at least partly determined by tax minimisation efforts, and the widespread practice of subcontracting (Elliot, 2012), rather than simply employers' responses to uncertainty and the business cycle. It suggests scope for policy interventions to address the issue. These will be discussed later, in Chapter 6.

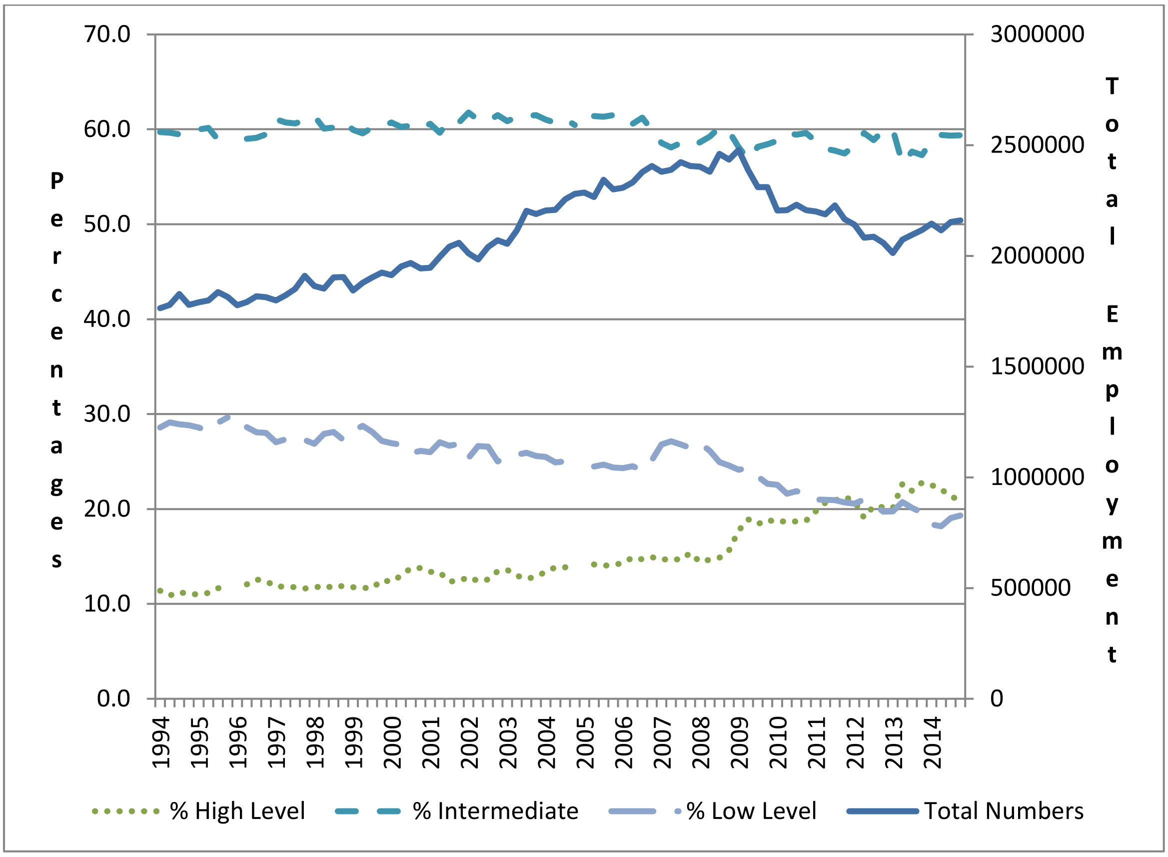
2.3.2 The construction dataset

The main purpose of the analysis in this chapter is to understand better the response of the UK construction sector to the business cycle, in particular, the structural issues, as well as recruitment and training responses. In order to do this the following subsections, use a specially developed dataset covering the construction sector. The data includes details of the age, skills, training, retention and recruitment of the construction workforce from the quarterly Labour Force Survey (LFS). This LFS data is linked to quarterly construction sector activity data to provide productivity indicators and allow linkage between activity and human resource indicators. The LFS data covers 86 quarters from January to March quarter of 1994 to the April to June quarter of 2015. This data linkage provides the basis for descriptive analysis in this chapter and further econometric analysis in Chapter 4.

2.3.3 Construction skills data

Using the quarterly Labour Force Survey (LFS), it is possible to obtain data on the current highest level of qualification. While qualifications do not necessarily map on to competence, they do provide a useful proxy measure of skills. These qualifications are broken down into high-level qualifications. These includes university level qualifications as well as Higher National Diplomas (HNDs). The classification also includes intermediate-level qualifications and low-level qualifications that include those with Level 1 National Vocational Qualifications (NVQs) and no qualifications Figure 2.2 presents this quarterly data for the construction sector over a 20-year period.

Figure 2.2: Total construction sector headcount and breakdown by skill level, 1994 - 2014



Source: Own Analysis of Quarterly Labour Force Survey Data
Note: Educational data gaps in the January to March quarters of 1996 and 2005 due to data collection methods

The figure shows a long-term trend of reduction in the proportion of the construction workforce with low-level skills; that is NVQ level 1 or no qualifications. Interestingly, just at the peak of construction employment in 2007, there was a small upturn in demand for those effectively without qualifications. The proportion with intermediate level skills remained essentially constant, with the drop in low-level skills mirrored by an increase in those with high-level skills.

Even as the recession hit in 2008, and headcount started to drop, the proportion of construction workers with high-level qualifications continued to rise. This rise indicates that those with low, or no, qualifications were much more likely to be made redundant by the sector.

Despite, this upskilling within the construction sector over the last twenty years, this needs to be evaluated in the context of an overall upskilling of the UK workforce. Table 2.4 provides such an analysis. This data shows that the increase in high-level skills in the construction sector is comparable with the overall increase in the workforce. By comparison, the decrease in low-level skills in the construction sector has been slower than in the workforce as a whole. So despite the changes the construction sector remains a low-skilled sector. This means that while finding staff might be easier in the future the sector will not benefit so much from the increase in graduates.

Table 2.4: UK workforce and construction workforce by educational level, 1994 and 2014

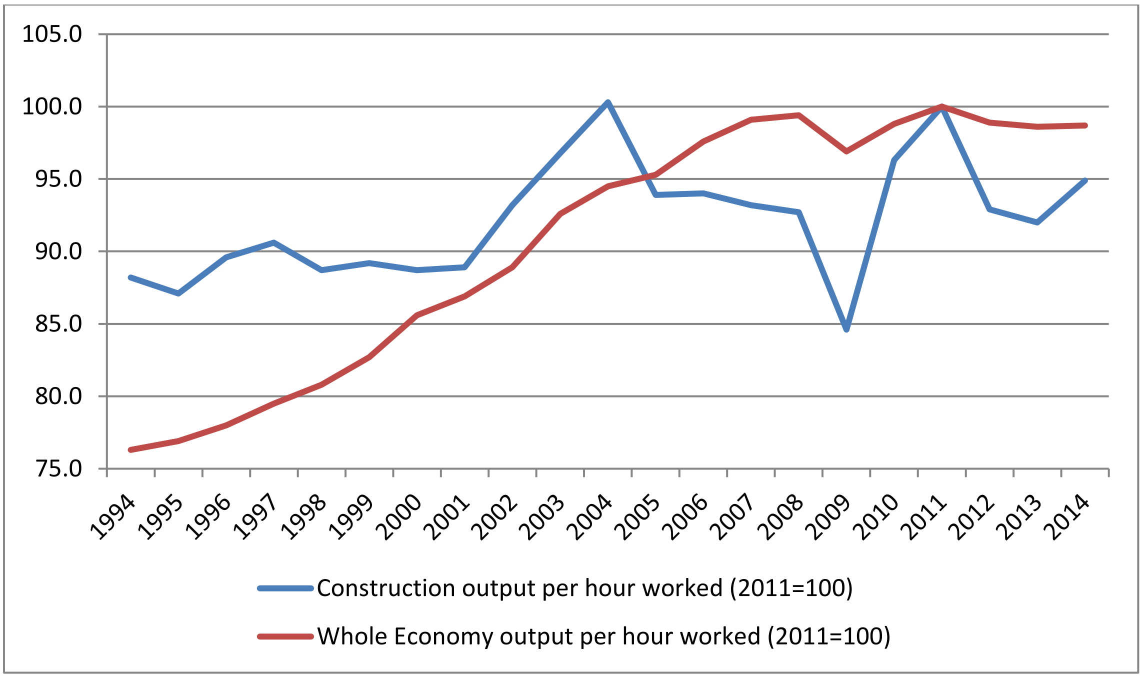
	1994		2014	
	Workforce	Construction	Workforce	Construction
High level	21.2	11.4	39.5	22.5
Intermediate level	44.8	59.7	44.5	58.8
Low level	34.0	28.6	15.8	18.4
Total	3,909,281	1,763,745	32,520,208	2,145,536

Source: Own analysis of the Labour Force Survey

2.3.4 Construction productivity

Over the long-run productivity increases can make a large difference to the number of workers needed to produce the same amount of output. This means that over the period of the LCT the rate of productivity change can be critical. Productivity is easier to define than skills and data on output per hour worked, a more robust measure than simply per employee, is available. Figure 2.3 shows the trends in construction sector productivity, as measured by output per hour worked, compared with the whole economy. This chart shows that, overall, there was a small dip in productivity in the UK in 2009, but after that productivity has been flat, compared to a steady growth between 1994 and 2008. In comparison, the picture for the construction sector has been much more complex. In part, a smaller sample is more likely to show some random variation. However, the pattern is more extreme than would be expected. This probably reflects measurement issues with the construction output data and is addressed in more detail in Chapter 4 where alternative productivity measures are examined. However, despite the problems with the data and many fluctuations around the trend, overall the construction sector has not shown much productivity growth since 1994. If this pattern actually reflects future construction productivity, there may be problems with the LCT as this productivity increases reduce the expense and the number of workers needed to achieve the transition.

Figure 2.3: Construction and Whole Economy Output per Hour Worked in 2011 prices



Source: ONS Labour Productivity Data

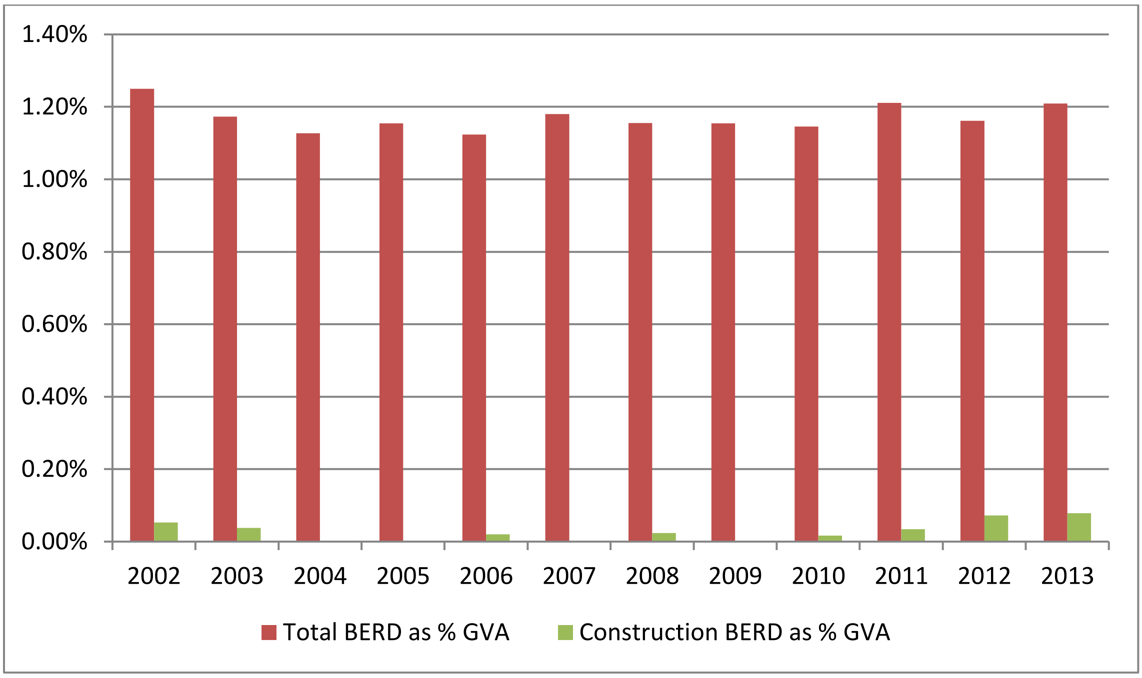
For a variety of reasons such measures of construction productivity are considered to be inaccurate (Abdel-Wahab et al., 2008). The main problem appears to be the sample frame for the construction activity survey, with firms moving in and out of the sample. However, there have also been important failures in generating a consistent price index for the sector, especially for the period when the production of the index was outsourced. These problems led to the price index and subsequently the construction activity data losing their status as National Statistics. As a result, much of the later analysis in Chapter 4 and 5 is based on an alternative measure of construction activity, Gross Fixed Capital Formation.

2.3.5 Construction innovation capacity

As stated in the introduction, technical change and innovation will be key in reducing the UK's carbon emissions in order to achieve the LCT. Therefore, it is important to examine how this may impact on the construction sector, which will be key in building and installing low carbon technologies. Importantly, in the context of this thesis, innovation refers to changes to the technologies currently available to the sector. It also, includes innovation occurring outside the sector in the construction materials supply industries, which are rarely included in the measures of construction innovation (Winch, 2003). However, it should be noted that although construction workers constantly innovate as they develop new ways to address problems that they face on-site, this form of innovation is not explored here. This means that this thesis only examines systems-wide innovation, rather than site specific innovation.

Innovation capacity covers the ability to generate and adopt new technologies and techniques. Innovation capacity is a broad concept and, as such, is difficult to measure directly. However, data covering annual Research and Development (R&D) expenditure is available for the construction sector. To compare levels of expenditure, this is usually expressed in terms of a percentage of GDP (Gross Domestic Product) or the sectoral equivalent GVA (Gross Value Added). Figure 2.4 shows that the construction sector spends a far smaller proportion of its value added than the UK economy overall. In 2013, the UK business sector spent 1.21 per cent of UK GDP on R&D during the same period the construction sector only spent 0.08 percent of its GVA. The data suggests that recently construction sector R&D spend has been increasing, but this is from a very low base. If construction sector R&D is the main driver of future construction innovation this is worrying in terms of future innovation and productivity improvements.

Figure 2.4 Business R&D Expenditure as a percentage of Gross Value Added



Source: ONS BERD data and ONS GVA data

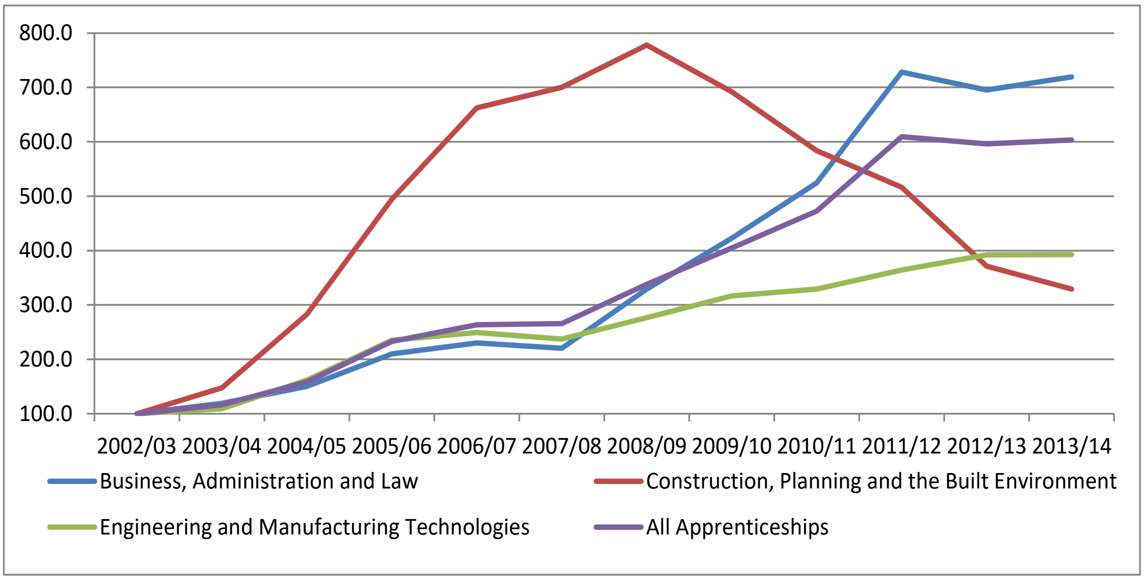
This R&D analysis reinforces the view from the literature that the construction sector is poor at innovation (Gann, 2000). However, there is a counter argument, that despite low R&D spend and low development of new technologies within the sector, the sector adopts innovations developed elsewhere in the construction materials producing sectors (Winch, 2003).

2.3.6 Construction training

If the LCT is to be successfully achieved then the construction sector must have sufficient numbers of appropriately trained workers, with different levels of skills, in place as the pace of the transition increases.

One feature of the provision of intermediate skills in the UK over the last few years has been the renewed emphasis on apprenticeships (Abdel-Wahab, 2012). Apprenticeships have benefits over other patterns of college based vocational training regarding rigour and linkage to employers' requirements (Gambin et al., 2012). However, the data on apprenticeship awards suggest that the model is not working so well for the construction sector (Hogarth and Gambin, 2014). Figure 2.5 reveals an interesting pattern; this shows that in the period between 2002/03 and 2008/09 construction apprenticeship awards grew at a faster rate than all apprenticeships and the comparator subject areas. Then as the construction sector activity collapsed after the 2008 crisis, so did the number of apprenticeship awards. This suggests greater volatility in the take up of apprenticeships by employers in the sector.

Figure 2.5: Apprenticeship awards by selected subject area indexed to 100 in 2002/03



Source: SFA and BIS FE Data Library: Apprentices

The collapse of construction apprenticeships at a time when they had the highest levels of policy support is problematic. Apprentices currently are the only Government supported mechanism for providing trade skills for the sector and this will have a long-term knock on impact skills levels within the sector. If the sector is going to return to the pre-crisis skill levels much greater efforts will be needed to recruit, train and retain skilled workers within the sector.

In Chapter 6 the thesis proposes Government intervention, via infrastructure investments, to maintain construction activity levels and training during future recessions.

2.4 The business cycle and technical change

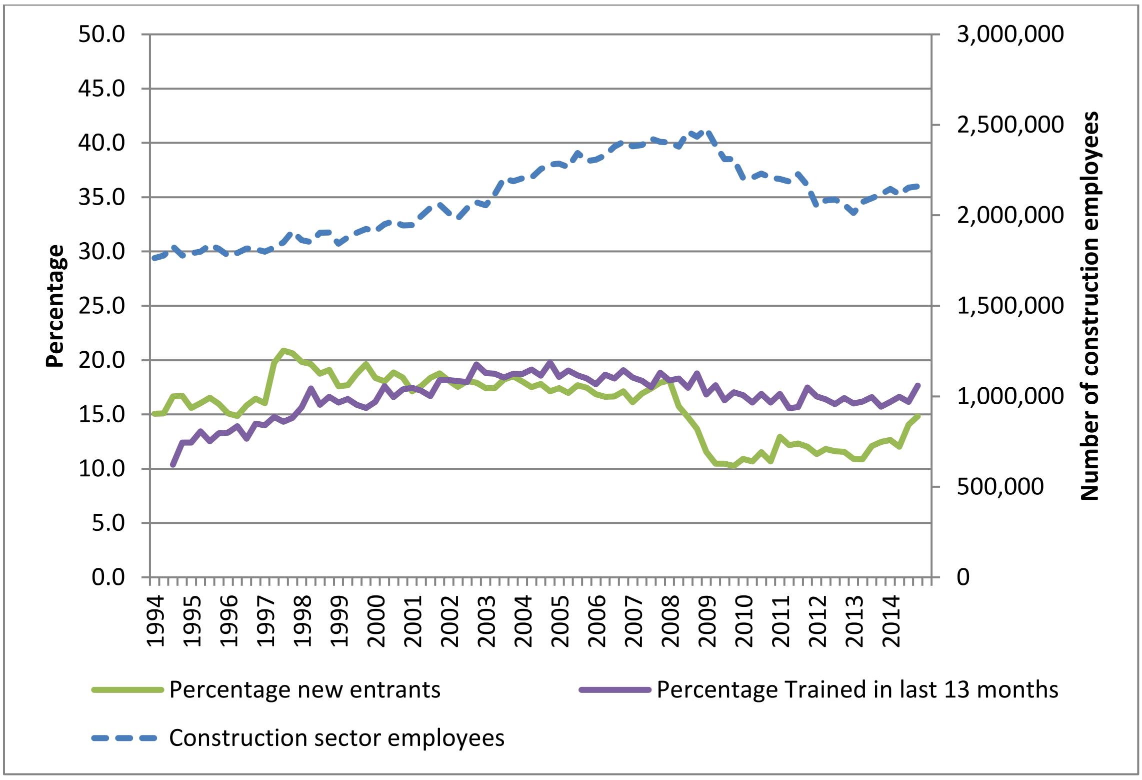
If the construction sector is going to build the necessary low-carbon infrastructure and retrofit existing buildings to be much more energy efficient, then the sector will have to improve its ability to respond to external shocks (Rodrik, 1999). The two main types of external shocks are business cycle caused economic shocks and technical change caused technology shocks. The subsections below cover this issues in turn.

2.4.1 Response to the business cycle

The intimate relationship between construction sector activity and the business cycle has already been mentioned (Ghent and Owyang, 2010). The response of the construction sector to the business cycle is critical to understanding its structure, skills and innovative capacity. Figure 2.6 provides three data series from the UK Labour Force Survey (LFS) which is a quarterly household-based survey of labour market issues. The chart shows that the UK construction sector currently (October to December 2014) employs over 2.1 million people. This figure is less than a peak of just over 2.5 million employees in the summer of 2009 and is similar to the number employed in 2003. The chart also shows that the bulk of the reduction in staff numbers in the sector over the last few years came as a result of a reduction in new entrants. New joiners, or those who were not in the sector six months before the survey, represented about 17 percent of the workforce between the years 2000 and 2008. However, by 2009-2010 new joiners represented roughly 10 percent of the workforce. New joiners tend to be younger and better qualified as well as being more likely to receive training than existing staff, which means this pattern has implications for skills in the long-run.

Importantly, even with the reduction in new joiners, the graph indicates that the proportion of the workforce receiving construction training has held up pretty well during the current recession. This resilience is possibly surprising as, often, when times are hard training is the first victim. However, it appears that employers in the sector realise that the pace of technical and regulatory change means that training remains important despite hard times. Nevertheless, the reduction in recruits to the sector is worrying, as less participation in training could potentially lead to future skills shortages.

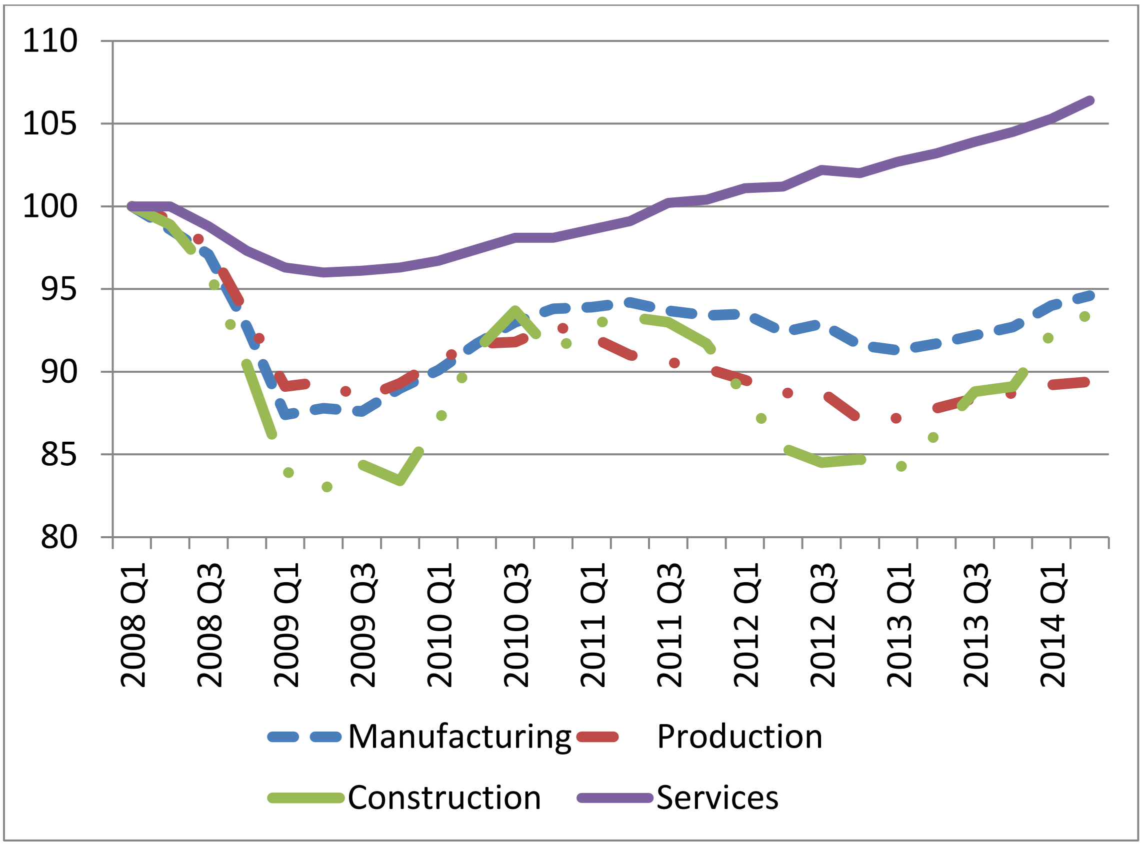
Figure 2.6: Size of the UK construction sector and percentages entering and training



Source: Own analysis of quarterly Labour Force Survey Data

The dominant feature of the workforce data is the impact of the recession on construction sector employment. This is shown in Figure 2.7 which provides an analysis of the construction sector output levels using seasonally adjusted chained measures compared to other sectors and the whole economy. Seasonal adjustment removes the strong impact of the seasons on construction activity from the data. The chained measures approach and use of deflators mean that the data takes account of inflation, so it shows real volumes of activity as with the national accounts (Eurostat, 2013). The chart shows the UK economy as a whole started recovering from the recession in 2009. However, significantly, it shows that the construction sector suffered a much more severe downturn than the rest of the economy and, in fact, suffered a double-dip recession, with a low point in activity in the second quarter of 2009 and the third quarter of 2011. The relative size of the construction sector at 6.3 per cent of total GDP in 2012 (ONS, 2013) means that the double dip in construction activity had a significant impact on the slow recovery of the overall economy. Importantly, by the end of 2014 both manufacturing and construction were still below the levels of output than in 2008. This pattern of more severe impacts of the business cycle on construction will be used when generating forecasts in the subsequent chapters.

Figure 2.7: UK GDP quarter on quarter growth, by sector, seasonally adjusted chained-volume measures 2008 Q1 = 100

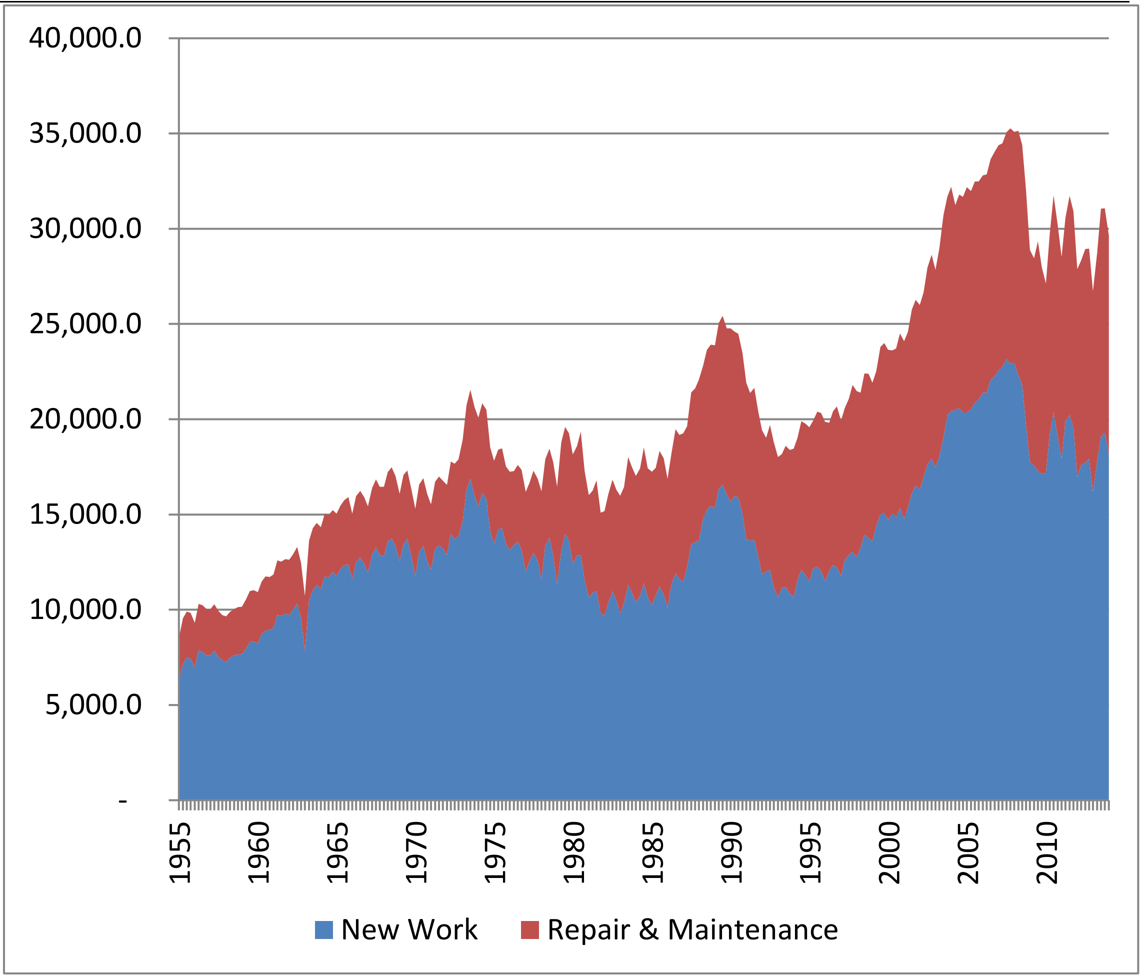


Source: ONS (2015) Statistical Bulletin Quarterly National Accounts, Q4 2014 – 31 March 2015, Office for National Statistics (ONS), London

Figure 2.8 provides a longer time series of construction sector output, also with the impact of inflation removed using GDP deflators. This series does not use the chained volume measures of the System of National Accounts, but the data is comparable to that shown in Figure 2.7. This chart shows a breakdown of construction activity into new build and repair and maintenance. As the data is not smoothed to take account of seasonal differences, there are obvious annual sawtooth-like variations. Importantly, it appears that repair and maintenance are largely unaffected by recessions, but that the main impact of recessions is on new build activity. This pattern is to an extent expected, with the volume of repair and maintenance mainly being driven by the size of the existing stock rather than to potential ability to sell new build. These patterns are important in terms of forecasting future activity. The chart also shows that the current downturn in construction sector activity has historical precedents. Although, if the recent double dip is seen as one long recession the current one is the most severe in recent history. The chart also shows the underlying growth in the sector, regardless of inflation. Population growth and general growth in the economy has driven this underlying growth. Both these factors drove a relatively rapid growth in construction sector activity over the twelve-year period from 1993 to 2005.

Overall, this shows that the construction sector is an important component of the economy and has a potentially significant impact on CO2 emissions. The charts show that the sector is also heavily influenced by downturns in economic activity, when construction activity and employment drops faster than in other sectors of the economy. This pattern of boom and bust influences the forecasting approach adopted in Chapter 5 of the thesis. However, unlike earlier recessions this one has been characterised by a maintenance of training levels which is encouraging regarding any future upturn in construction activity. The final observation is that the construction sector has grown, alongside the UK economy, despite the regular impacts of recessions.

Figure 2.8: Quarterly construction sector output in 2011 prices – 1955 to 2014 Q4



Source: ONS Statistical Bulletin Quarterly National Accounts, Q2 2014, ONS (2014)

2.4.2 Response to technical change

To achieve the necessary reduction in carbon emissions, the UK will need to implement new technologies to generate clean energy and reduce fossil fuel consumption. However, technical change, especially rapid technical change, can be very disruptive for employers. This disruption is especially the case when there are low levels of skills, as in the construction sector, which means that absorptive capacity is low (Antonietti, 2005). This is compounded by a construction sector specific tax-regime which encourages self-employment and tax evasion (Behling and Harvey, 2015). The main problem for the employers is the uncertainty about the longevity of the new technology. If widespread adoption of a technology is to occur and it will continue to be used for many years, then it is worthwhile training employees to use the technology (Barrett and Sexton, 2006). However, if those employees can then command a premium by becoming freelancers specialising in the new technology, then this deters further training and new technology adoption (Bennett and Ferry, 1990). This problem means that the usual response to technology shocks within the construction sector appears to be similar to that used in response to business cycle shocks. The organisational routines that seek to minimise risk by outsourcing, also slows the pace of adoption of new technologies (Green and May, 2003). It also means that training in the use of new technologies is often individually funded, rather than employer funded, further slowing the acquisition of the necessary skills.

The pattern of funding of training has led the UK Government to use the process of licencing to encourage and obligate higher levels of training across the construction sector. This process means that individuals, and often firms, have to acquire specified qualifications to perform certain functions or to access certain subsidies. This strategy has been particularly applied to ensuring that those installing domestic renewables and energy efficiency measures under the Green Deal are competent (Jagger et al., 2014). However, the reliance on people investing in their training and certification only works as an incentive for training when there is a perceived certain and profitable stream of future work. The reliance on individual funding, in turn, requires a consistent and stable policy environment. If policy is not consistent this may be problematic in terms of training. For example, the history of the UK Feed-in-Tariffs (FITs) for domestic solar electric panels produced a pattern of boom and bust and led to a reduction in training and certification activity (Muhammad-Sukki et al., 2013). Therefore, with the later introduction of the Renewable Heat Incentive (RHI), the Government used the more expensive strategy of offering training grants to encourage the take-up of appropriate training The role of policy responses to skills shortages are explored in more detail in Chapter 6.

3 – Skills in the Low-Carbon Transition

3.1 Introduction

This chapter provides the theoretical underpinning for this thesis. As such, it links the empirical sections to an underlying theoretical debate and provides a theoretical justification for the approaches used. As this thesis aims to understand the role of skills in the LCT, it is first necessary to develop a clear understanding the meaning of 'skills' and the 'low carbon transition'. In particular, this chapter focuses on the nature and causes of skills shortages, as these are seen to be the main risk that skills, or the absence of skills, pose to the LCT. Therefore, this chapter aims to address the third research question:

> *"What is an appropriate theoretical approach to understanding skills shortages?"*

3.1.1 Main points and summary

The critical elements of theory and theoretical development, as well as the evidence utilized by this thesis, is summarised in a series of points. Therefore, this chapter seeks to establish the following four assertions:

There is a lack of an adequate theoretical understanding of skills shortages

Skill shortages are poorly understood and poorly measured (Green and Ashton, 1992), partially as a result of the dominant neoclassical explanations of skill shortages (Cappelli, 2014) and the existing measures of skills shortages outlined in Section 3.2.2. The problem of understanding is especially the case in the context of the low-carbon transition (LCT) (Jagger et al., 2013). Equally, as will be shown later (Section 3.3.3), the dominant theory currently covering the low-carbon transition, the Multi-Level Perspective, does not adequately address skills issues. The absence of an adequate explanation of skills shortages leaves the low-carbon transition potentially at risk of disruption from unexpected skills shortages.

Evolutionary economics and the idea of coevolution of the institutions surrounding skills and technological change offer a solution

The thesis argues that evolutionary economics provides a structure that allows a clearer understanding of skills shortages (Section 3.4.1). Skills have an intimate relationship with technical change and innovation, with links to both technology development and technology adoption (Cohen and Levinthal, 1989). Also, skills and skills shortages need to be understood in the context of, and as coevolving alongside, skills supply (Leitch Review of Skills, 2006), skills demand (Lewis, 2008), technical change and technology adoption (Acemoglu, 1998). Additionally, skills' institutions and skills governance (Payne, 2008b), as well as skills utilisation (Payne, 2012) have a role to play. The, admittedly limited, evidence available suggests that the causes of persistent skills shortages are complex (Healy et al., 2012) and often linked to rapid technical change (Sabourin, 2001). It is then further argued (in Section 3.4.2 and 3.4.3), that varying lags between sub-systems of coevolving systems, as a result of inertia, can cause unexpected interactions between co-dependent, as well as coevolving, components of the system.

Skills institutions and skills governance have critical roles

The thesis argues that skills institutions and skills governance have critical roles in assessing and addressing the skills requirements of the low-carbon transition (PWC, 2010). The above arguments lead to a need to determine which occupations might cause disruptive skills' bottlenecks for the low-carbon transition and how to optimise the governance of low-carbon skills. Determining these potential problems that skills shortages may pose for the low-carbon transition is the core ambition of this thesis. Addressing these problems involves mobilising the available evidence, developing models and using scenarios to explore the pattern of skills demand compared with the current pattern of supply. Chapters 4, 5 and 6 contain the evidence and the scenarios.

The construction sector will be central to the low-carbon transition and should be a focus

To achieve the low-carbon transition a massive increase in infrastructure investment and construction activity will be necessary. Furthermore, as is argued in Chapter 2, since the construction sector will be responsible, directly or indirectly, for a large proportion of the required reduction in carbon emissions, it will be central to the low-carbon transition. Given this importance, and the availability of extensive literature and secondary data covering the construction sector, it will be the focus of this thesis.

Also, it has been argued that responses to the business cycle and technology shocks produce a fragmented structure for the construction sector (Forde et al., 2009). Therefore, the sector becomes particularly poor at training (Forde et al., 2008) and innovation (Gann, 2000). It is further argued that these structural weaknesses, combined with skill shortages, leave the construction sector poorly able to respond to the demands of the LCT (Jagger et al., 2013). In addition to the business cycle shocks, the construction sector will have to respond to technical shocks and a rapid pace of change as a result of the LCT (Pearson and Foxon, 2012). Chapter 2 expands these issues.

The actual technologies adopted as part of the LCT in the UK will influence the pattern of skills shortages driven by technological change in the construction industry. There are a range of scenarios available (Ekins et al., 2013; Foxon, 2013; and DECC, 2010a).

3.1.2 The structure of the rest of the chapter and thesis

This chapter has a further six sections addressing, and expanding upon, the above points broken down into the following areas:

- 3.2 – Defining Skills and the Low-Carbon Transition – covers the first part of issue one and

- 3.3 – Problems with Existing Theories –covers the second part of issue one
- 3.4 – Tripartite Model of Skill Shortages – covers issue two
- 3.5 – Skills Institutions and Skills Governance – covers issue three
- 3.6 – Implications for the Thesis – draws out where the theory outlined is used in the thesis.

3.2 Defining skills and the low-carbon transition

As the thesis is designed to address policy issues, it is important to use definitions of skills, skills shortages and the LCT used in policy circles and that relate to policy issues. This section also explores the role of the construction sector in the LCT. The following sub-sections aim to do this.

3.2.1 What do we mean by skills

The term 'skills' has many meanings, and the definition used in this thesis is a broad interpretation of the concept. This is necessary, as the thesis covers a broadly defined conception of skills, as outlined in this quote:

> *"A skill can be defined as an ability or proficiency at a task that is normally acquired through education, training and/or experience. It can at times be synonymous with the related concepts of competence, expertise, knowledge and human capital." (Tether et al., 2005: 5)*

The advantage of this definition is that it takes the understanding of skills beyond the simple one of actual skills and competencies, such as the ability to perform specific tasks. It also produces a definition that is closer to human capital (Becker, 1964). It also links to the employers' view of skills as the capacity to undertake tasks rather than simply the possession of qualifications. Tether et al.'s definition also includes the processes of education, training and experience that lead to skills and the ability to express and utilise the skills in the context of work (Attewell, 1990). However, a limitation of this definition is that as competence and experience are difficult to measure, it is often necessary for employers (Reio and Sutton, 2006), to use qualification and years of education as proxies for possession of skills (Le Deist and Winterton, 2005). Therefore, different employers both reporting 'skills shortages' may in fact be experiencing different problems with different causes (Oliver and Turton, 1982). Even here, there is the suggestion that national systems of education are so different that it is very difficult to compare qualifications internationally (Clarke and Winch, 2006). 'Human capital' refers to the aggregate of qualifications, years of training and experience (Becker, 1964). However, by using some data sources in this thesis, it is possible to get information at the sectoral or occupational level of the amount of training being provided by employers, and this becomes a useful more direct measure of potential innovative capacity (Jones and Grimshaw, 2012).

For the transition to occur widely adopted innovations, based on targetted R&D, will be needed. Skills have been shown to be important for R&D and innovation (Toner, 2011). Oke et al., (2012) show that the interaction between innovation policy and innovation oriented human resource practices are critical for successful innovation. Using data from three hundred and four large Italian establishments, Neirotti and Paolucci (2013) showed that training plays an important role in the acquisition and assimilation of new knowledge. D'Este et al., (2014) argue that a bundle of indicators they label as human capital is important for reducing barriers to innovation, especially in term of barriers produced by knowledge shortages and market uncertainties.

Regarding diffusion and adoption of low-carbon innovations, skills have also been identified as critical for 'absorptive capacity' (Cohen and Levinthal, 1989), or the ability to benefit from innovations occurring elsewhere (Griffith et al., 2004). Given that many of the innovations underlying the LCT already exist (Wiseman et al., 2013) it is possible that absorptive capacity is, in the short term, more important than R&D.

The evidence on the impact of different levels of skills is weak. There is some evidence that higher level skills (Piva and Vivarelli, 2009), especially postgraduate level skills, are important for R&D (Roach and Sauermann, 2010; Lindley and Machin, 2013). While there is slightly weaker evidence that intermediate level skills are as important as higher level skills regarding absorptive capacity (Toner and Dalitz, 2012).

Another distinction made, within the neoclassical tradition, about skills is the difference between general and specific skills (Becker, 1964). 'General skills' are transferable to other employers and are often certified by qualifications. 'Specific skills' are those that are specific to the current employer and, as such, are not transferable. Human Capital theory argues that employers have incentives to provide specific skills, but less incentive to provide training leading to general skills, as this could end up subsidising their competitors (Becker, 1962). Since many skills involved in the LCT are likely to be general skills, this is a disincentive for firms training their staff in low-carbon skills.

Therefore, given the complex environment within which skills are viewed, measured and used, as outlined above, it is equally likely that there are a range of other issues, in addition to training and human capital, that link skills to the LCT. Therefore, when exploring skills and the LCT, a wide range of factors and influences need examination. In particular, the thesis will explore the role of skills institutions that develop qualifications and provide training. Additionally, this complexity and interaction between multiple factors is difficult to reconcile with a system that is solely driven by market forces. Section 3.2.1 explores the problems with the neo-classical view of labour market issues.

3.2.2 Measuring skill shortages

For this thesis skills, shortages are defined as existing when employers state that they find staff with particular skills hard to recruit or retain (Frogner, 2002). Employers identify skills shortages in various ways, for example, sometimes they report that existing staff and recruits lack the required skills to carry out the work required of them (Green et al., 1998). However, they also often use the same term to relate to problems recruiting staff with the required skills (Greig et al., 2008). Although, the two types of skills shortages usually have the same consequences for the employer, they need different policy responses. Problems with existing staff require training provision, while problems with recruitment usually require supply-side responses (Toner, 2003). Training provision can either be encouraged in-house, sometimes by regulation, or externally, often by providing subsidised training. Supply-side responses include educational and training interventions and changing careers advice based on new skills foresight studies.

This multiple understanding of what is meant by employers by skills shortages is returned to later, as effective policy development needs the concept to be broken down by the different drivers of the problem, for example demography, basic education and training provision.

The concept of skills shortages is 'contested', with some authors arguing that reliance on employers' views alone cannot provide a sufficiently grounded basis for understanding skills shortages and that alternative definitions are required (Holt et al., 2010). Skill shortages have long been a focus of policy interest (Frogner, 2002). A common response to skills shortages is immigration (Ruhs and Anderson, 2010). Therefore, most of the definitions are derived from the attempts to define occupations that have immigration waivers (Anderson and Ruhs, 2008) or occupations that need greater training and education efforts (Holt et al., 2010).

However, this approach compared with others that measure relative pay increases (Ruhs and Anderson, 2010), or reduced turnover (Stevens, 2007), is less well-linked to the problem as experienced by employers (Greig et al., 2008). Problematically, skill shortages can occur in limited geographical areas, and in some narrowly defined occupations, meaning that larger and more detailed surveys are required to explore the phenomena (Holt et al., 2010). Therefore, to encompass this broad range of issues that can impact on skills availability, this thesis adopts the most commonly used definition of skills shortage occupations, which is: *those occupations* *that are hard to recruit*. The use of this definition is selected as it links to a range of survey and qualitative data and is readily understood. Section 3.4 examines the causes of skills shortages, as part of the development of a working theory.

Unfortunately, many skills shortages are 'latent' in that employers do not know that they require, or would benefit from, the missing skills. Pro Enviro argued that latent shortages are a particular problem for low-carbon skills as employers have less experience of the skills required or the markets that might emerge (Pro Enviro, 2008). This aspect of low-carbon skills causes problems when there is an employer-led skills system as currently operated in the UK (Payne, 2008a). The employer-led concept means that the Sector Skills Councils are dependent on employers within their scope for funding. The issue of employer-led skills policy is explored further in Chapter 6.

3.2.3 Consequences of skills shortages

The consequences of skills shortages are varied and depend on the sector; the technologies used and other factors, such as the skill endowments of the competition and the size of the employers involved. However, generally skills shortages manifest themselves in the form of productivity gaps and lower outputs. Additionally, skills shortages, and this more often applies to latent skills shortages, can lead to sectors and employers not taking advantage of the latest technologies, techniques or potential products. Skills shortages lead to lower productivity than otherwise expected (Haskel and Martin, 1993a). Skills shortages also influence firms' behaviours, with reduced recruitment and slower expansions following periods when shortages occur (Stevens, 2007).

More specifically, within the construction sector, skills shortage can lead to delays in projects (Assa and Alhejji, 2006) and, in part, lead to cost overruns (Cantarelli et al., 2010; Jennings, 2012). This is a particular issue for the transition. The LCT has a tight timetable and needs to change the existing energy system faster than all previous transformations of energy systems

(Fouquet, 2010). Equally, the cost of the LCT is already high (Stern, 2006) and cost overruns are not affordable. For these reasons skill shortages impacting on the LCT should be avoided.

Avoidance of these shortages is key to the success of the Low Carbon Transition and requires an in-depth analysis such as this thesis attempts.

3.2.4 The role of construction in the low-carbon transition

The LCT primarily involves the radical reduction, and in part elimination, of CO2 emissions from the burning of fossil fuels. The term derives from a UK Government 2009 publication entitled 'The UK Low-Carbon Transition Plan'. This plan was a response to the 2008 Climate Change Act, which mandated carbon reduction targets for the UK. It is necessary to reduce CO2 emissions by 40 to 70 percent of the 2010 emissions by 2050 to meet the target of limiting temperature rises to 2 degrees Centigrade (IPCC, 2014). The UK is, as a result of the Climate Change Act, committed to an 80 percent reductions in emissions by 2050 and the complete decarbonization of the electricity supply, as well as many other dramatic changes. The emissions reduction, in turn, will require massive investments in new energy infrastructure and the refurbishment of most existing infrastructure and dwellings to ensure that they are more energy efficient. Globally, this will involve investments in green infrastructure of between 36 and 42 trillion US$ between 2012 and 2030 and will require doubling current investments to 2 trillion US$ per year (Kaminker and Stewart, 2012). The new renewables in the UK will involve investments of the order of £45 billion pounds between 2015 and 2020 or £60 billion, including nuclear and CCS (DECC, 2015a), or about £12 billion per annum. In 2014, a record £8 billion was spent on renewables investments suggesting a 50 per cent annual increase in investment is required. Clearly, this will have a corresponding increase in renewables-related construction activity. Additionally, there will be large expenditures on retrofitting domestic, commercial and industrial properties to ensure that they are as energy efficient as possible. The energy intensive manufacturing sectors that include iron and steel, chemicals, oil refining food and drink, cement, pulp and paper, glass and ceramic sectors will need to replace existing infrastructure and techniques with less polluting versions. This energy intensive manufacturing investment has been calculated to be £16 billion between now and 2050, compared with a business as a usual figure of £6 billion (WSP Parsons Brinkerhoff and DNV GL, 2015).

All of this will be on top of a growth in construction activity, as the UK emerges from recession. These pressures will add to the demand for construction skills and may help create skills shortages and, potentially, disruptive skills bottlenecks which will impede the LCT.

3.3 Problems with existing theories

There are problems with the prevailing neoclassical approach to understanding skills and skills shortages when applied to the LCT. These problems are explored below, before Section 3.4 proposes an alternative approach. Equally, the dominant theory used to explore issues around the LCT, the multi-level perspective, does not include skills issues. Again, these problems are explored before proposing an alternative below.

3.3.1 Problems with the neo-classical view of skills shortages

The thesis argues that conventional economics, especially the neoclassical economic viewpoint, fails to explain adequately why skill shortages exist or how to address them. The core problem with neoclassical economic attempts to explain the nature of skills shortages is the belief in the equilibrating force of the market. The assumption of equilibrium almost precludes the idea of skills shortages, especially persistent skills shortages, as the core concept of equilibria assumes that these shortages will be filled by employers paying more or potential employees accepting lower wages. Market-based theories of skills suggest that shortages should be short term while employers change the rewards offered, or employees obtain the required skills (Stevens, 2007). However, skills shortages are persistent and a particular problem when the economy emerges from recession (Bosworth, 1993). Conversely, others from within the neoclassical tradition maintain that there is little real evidence of shortages (Arrow and Capron, 1959; Freeman, 2006), only employers' reports (Cappelli, 2014). It is argued theoretically, from within a neo-classical position, that over-education is more likely to be a problem than skill shortages (Cappelli, 2014). This suggests that from within the neo-classical tradition there should be no low-carbon skills problem.

There is evidence that skills shortages relate to whether firms adopt a low-technology, and low-productivity approach rather than a high-technology, high-productivity approach (Mayhew and Keep, 2014). This debate is often expressed regarding the 'product strategies' adopted by firms with innovative higher productivity strategies, which are associated with higher levels of skills (Mason and Constable, 2011).

Despite the neoclassical tradition that sees skills shortages as temporary and self-correcting, skills shortages remain an important issue amongst employers and policy makers and immigration of skilled workers is a common solution. Therefore, many of the definitions (Migration Advisory Committee, 2008), and the most reliable evidence of skills shortages are collected by migration bodies (Migration Advisory Committee, 2013). These definitions tend to use employer reports and have no theoretical underpinning. Therefore, there is a requirement for an alternative and more detailed explanation of what causes skill shortages.

The evidence covering the linkages of skill shortages to other labour market features provides the beginning of a theoretical understanding of skills shortages. Haskel and Martin, (1993b) suggest that skills shortages are at least partially driven by low levels of training. The same authors examine why skill shortages in the UK persist, despite rising levels of training and educational attainment. They later found that higher technology establishments suffered higher levels of skills shortage. Importantly, they suggested that persistent shortages were due to technical change (Haskel and Martin, 2001). This is of particular interest when considering the reliance on the rapid and massive technical changes necessary to achieve the LCT. Using Australian data, Healy et al., (2011) also show the persistence of complex skills shortages involving technical change, alongside educational failure, low levels of training, low pay and other institutional factors. They also argue that analysis of the data showed that no single simple cause.

In practice, the neoclassical-based, academic debate around skills is largely about high-level skills. High-level skills are taken to mean university level education. There is also a more specialised literature covering those with doctoral level qualifications (Lindley and Machin, 2013). In part, the doctoral comparisons are used because it is easier to establish comparability at this level, but also it is easier to establish a linkage to R&D for those with a doctorate (Thune, 2010). In terms of the key role of construction, which is heavily reliant on workers with low level and intermediate skills, this neo-classical focus on higher level skills is unhelpful. Indeed, Toner, (2010) provides a review of the evidence surrounding the role of vocational skills and innovation. This concludes:

> *"Despite observing the importance of the direct production workforce and the training systems which produce it, the discipline has not engaged in detailed studies of the role and significance of VET in innovation. These gaps are however, being increasingly recognised. '[A]cademic research on innovation is still dominated by an R&D mindset, so that the characteristics and drivers of non-R&D based innovation continues to be neglected…" (Toner, 2010: 90)*

Despite the paucity of evidence, there is a strong suggestion that vocational skills are important for the adoption of technologies developed elsewhere and to the process of incremental innovation (Garcia-Quevedo et al., 2011). Equally, there is evidence; that skills gaps were more likely to be reported at the intermediate level of skills (Kochan et al., 2012).

The usual explanation offered for skill shortages within the neoclassical viewpoint, are a series of 'frictions' that slow and disrupt the working of the labour market. Primarily, the concept of frictional labour markets was developed to explain the extent and pattern of unemployment

(Mortensen and Pissarides, 1994). 'Frictions' are caused by imperfect information which means that either or both, parties to labour market negotiations cannot make accurate decisions (Mortensen and Pissarides, 1999). The concept of 'frictions' has also been applied to the acquisition of skills and skilled workers by employers (Wasmer, 2006). In particular, the idea of search costs acting as a friction for recruitment is also used. Essentially, neo-classical economics explains skills shortages regarding imperfect labour markets and other problems that intervene and cause the market not to operate optimally (Acemoglu, 1997). However, there are limitations to this viewpoint, especially regarding formulating policy to address these problems.

Historically, again within the neoclassical view, skills have been split into general and specific skills. This concept was introduced by Becker (1964). Becker argues that employers are willing to pay to train employees in firm-specific skills. However, they are much less likely to provide employees with general skills that could allow them to get work with other employers. The problem of general skills is a particular problem if the training leads to a recognised qualification, as this signals to other employers that the employee has transferable skills and raises issues of retention when the employer considers investment in training. At the same time, employers are unsure about the real level of skills of those they recruit. Qualifications, to an extent, help employers to judge skills in advance. However, current employers are more likely to have a clearer idea of the skills of their employees, rather than a recruiting competitor (Garloff and Kuckulenz, 2005). Again, the idea of imperfect information and frictions are used to explain why some, if still sub-optimal, training occurs (Gerfin, 2004).

Another explanation of why some general training occurs, despite the theoretical reason it should not, is called 'wage compression'. This explanation argues that existing staff earn less than the new staff of the same competence. Effectively this allows employers to recoup the training costs of their long-term staff (Bassanini and Brunello, 2008). The previously mentioned frictions, and the wage compression, are all seen as distortions in the labour market that allow greater levels of training than theory would suggest. However, overall, skill deficiencies are seen as resulting from market failures (Schömann and Siarov, 2002; Brunello and De Paola, 2004). Market failure is largely a term that covers most of the factors that lead to sub-optimal levels of training (Brunello and De Paola, 2009). Despite the belief in market failure, it is equally possible that individuals and their employers are making rational choices from their perspectives. Employees are always likely to be less skilled than optimal because employers are unwilling to train people who might then leave to work for a competitor. Similarly, employees are less likely to fund training if they do not believe their employer will reward the qualification.

A more recent paper reinforces the importance of vocational skills and concludes:

> *"The innovation studies literature points unambiguously to the important role of the VET system and vocationally trained workers in generating, adapting and diffusing incremental innovation in production and R&D." (Toner and Dalitz, 2012: 422)*

Another aspect of the linkage between vocational skills and innovation that will be explored further in Chapter 6 is the role of skills institutions in anticipating innovations and their adoption regarding providing appropriate skills. The institutions surrounding skills that determine, to differing extents, the pattern of skill formation by level and discipline are critical to ensuring and adequate supply of skills. The role and institutional governance of these bodies are also explored in more detail in Section 3.5.

Importantly, for the development of an alternative perspective Thelen (2004) emphasises the evolving nature of skills institutions that develop specific national characteristics. However, Thelen uses this insight to understand how these institutions have evolved and what has driven their different national characteristics. By comparison, this thesis uses the evolving nature of skills institutions as the basis for a coevolving system and an empirical forecast model. This locates the institutions within a more complex co-evolving system involving technical change and underlying economic growth. This is the first time such a coevolutionary model has been applied to the forecasting of skills requirements. By explicitly modelling technical and institutional change as well as economic growth this approach provides a more detailed and accurate forecast over the longer-term of the LCT.

3.3.2 The multi-level perspective

The dominant theoretical approach used to examine the change from the current resource and emissions intensive culture to a more sustainable low-carbon culture has been Transitions theory (Grin, 2016). Within the transitions tradition, the Multi-Level Perspective (MLP) has been very influential. The MLP theory largely originated in the Netherlands and is based on a relatively tight-knit, cross-citing group of researchers (Chappin and Ligtvoet, 2014). Frank Geels (2002a; 2005b; 2011, 2014), has mainly defined the main MLP approach.

The Multi-Level Perspective (MLP) has been central to the mainstream version of Transitions theory. The MLP is also derived from the evolutionary economics and National Systems of Innovation (NSI) approach (Nelson, 1993; Freeman, 1995; Street and Miles, 1996; Lundvall et al., 2002; Patel and Pavitt, 2006; Markard and Truffer, 2008). Given the centrality of the MLP to low-carbon literature, and the link to evolutionary economics, it seems sensible to use it as the basis for an understanding of the impact of skills on the LCT within the thesis

Unfortunately, the MLP makes little reference to skills. The only examples identified are in the context of niche development (Schot, 1998) and regime maintenance (Rip and Kemp, 1998). Therefore, although elements of the MLP can be used to understand the role of skills in the LCT, it is necessary to work from first principles to explore the issue in more detail. The next section endeavours to develop a theory of skills shortages based on the coevolution of skills, institutions and technical change. Within this coevolving system with significant inertia by any component driving the development of skills causing skill shortages.

3.3.3 Failure of the market failure approach

Essentially, the neo-classical approach to views skills shortages as a form of market failure. The market failure view also determines the standard policy response to skills shortages which views the solution in terms of re-establishing the market (Cook et al., 2012). However, the policy ideas around skills and skill shortages continue to be contested (Keep, 2009) and, sadly, despite much effort, and costly interventions, skills shortages persist. Therefore, it is easier to argue that the existing way of thinking about skills shortages in terms of market failure has, in practice, failed or is inadequate. The idea that the market failure approach has failed is not new and emerges in other areas of economic life. The idea of the failure of market failure has been applied to environmental policy (Anthoff and Hahn, 2010) and innovation policy (Mazzucato and Penna, 2015). If the existing theoretical approach does not work, it is necessary to develop an alternative. Later sections put forward a new and alternative view of skills shortages which are based on evolutionary economics and argues that skills, institutions and technical change coevolve.

3.4 Tripartite model of skills development and shortages

The task of developing a working theory of the causes of skills shortages has been broken down into two main sub-sections, one covers the co-evolution of skills, institutions and technical change and another, dealing with the impact of lagging components of a co-evolving system. The new theory follows an introduction to evolutionary economics. While the section ends with a brief examination of how organisational routines can lead to skills shortages.

The idea of the coevolution of components of systems is a concept derived from evolutionary economics. This idea is then extended for this thesis, to consider that skills are produced as a result of a coevolving system consisting of economic activity, technical change and institutions. This section examines the literature that supports this argument and indicates where existing theories differ from the thesis.

3.4.1 Introduction to evolutionary economics

Technical change and innovation is central to the evolutionary economic point of view. It is also central to the success of the LCT and, therefore, represents the central theoretical perspective for this thesis. In contrast, neoclassical economic theory essentially views technical change and innovation as a residual, once the effects of capital and labour have removed from economic growth (Solow, 1956). The evolutionary approach therefore provides the more nuanced understanding of innovation than neo-classical approaches. One author described the differences as follows:

> *"These differences can be characterized by saying that the neoclassical theory sacrifices a significant amount of realism in terms of describing the actual innovation process in return for a quantitative modelling approach that favours strong analytical consistency, while the evolutionary approach embraces the micro complications of the innovative process and applies a more eclectic approach." (Verspagen, 2006: 492-493)*

One of the strengths of the evolutionary approach is that it draws heavily on economic history and looks at the multi-dimensional details surrounding particular innovations or clusters of innovation. Another advantage of using an evolutionary economics approach is that the tradition gives priority to institutions and national differences. Since skills are deeply embedded in National Systems of Innovation (Lundvall et al., 2002) and national varieties of capitalism (Hall and Thelen, 2009) it is best to examine skills within the context of these national institutions (Evans and Stroud, 2014). Fortunately, the evolutionary economic tradition embraces the institutional analyses, so it is much better suited to the analysis of skills than neoclassical economics.

Evolutionary economics, as described by Nelson and Winter (1982), is based on a critique of neo-classical economics and, in particular, the description of how economic actors base their decisions. They find the idea of perfect market knowledge untenable and the detailed calculations of market optimisation unlikely as they argue that economic actors base their decisions on routines rather than calculation. These routines derive from the skills that they have acquired in the past and operate, to a degree, like computer programs (Nelson and Winter, 1982: 74).

The concept of routines from Nelson and Winter, as well as the derived concept of co-evolution, will be used in the next two sub-sections and provide critical theoretical insights.

3.4.2 Co-evolution of institutions and economies

Given that institutions play a critical role within economics and provide a mechanism for reinforcing and moulding the routines of individual economic actors (Nelson, 2002), they are worthy of examination. Importantly, it is maintained that these institutions co-evolve with economic developments and technical change (Nelson, 1994). This concept has led, in part, to the idea of national systems of innovation where national institutions co-evolve with the ability to innovate (Freeman, 1995; Lundvall et al., 2002; Soete et al., 2010).

Foxon (2011) notes the importance of the co-evolution of institutions and technical change in the LCT. Foxon uses the terms micro-meso-macro to define the levels of a multi-level approach. This approach is similar to, but perhaps more generic than, the multi-level approach of Geels (2005b). However, in Foxon's approach the lowest micro level is more flexible than the niches of Geels, as change can occur at more levels and in many areas:

> *"So, our framework suggests that key events in the transition to a sustainable low carbon economy may occur through technological changes, forming of institutions, revisions to business strategies or changes in user practices, and how these changes interact with changes in natural ecosystems. Each of these types of change involves a role for agency, i.e. actors to actively influence change, through the consequences of any individual action will always be uncertain, as it is mediated through the interaction with existing structures ..." (Foxon, 2011: 2263)*

For the purpose of the thesis, if skills are entered into the coevolving system, an important extension of Foxon's ideas is possible and is one that could help to explain skills shortages. This addition is possible by conceiving of differential lags in the interactions between the components of Foxon's model. If skills are added and assumed to sometimes lag behind technical change as a result of inertia, or sometimes be in advance of technical change, interesting consequences could emerge. For example, this concept would allow situations where the presence of existing skills might enable and force the pace of technical change, as well as other situations where the absence of appropriate skills could impede or delay technical change. This extension of Foxon's coevolution idea produces the central theoretical concept of the thesis that: *skills, institutions and technical change coevolve, and differential pace of change by each of these sub-systems can produce features such as skill shortages*. This insight allows a range of other theories to be incorporated and allows the development of policy interventions that could ease the LCT.

However, there is also an alternative view of how skills develop and skill shortage emerge which is based on the concept of 'skills ecosystems' that started in Australia (Hall and Lansbury, 2006). The idea of skills ecosystems partly draws on the concept of low skill ecosystems. This approach argues that solutions to skills problems are not simply a matter of increasing supply, but that issues of skills utilisation also need to be addressed. Although, developed in Australia, the idea of skills ecosystems comes from the UK and is found in Finegold and Soskice's (1988) critique of training in Britain and Finegold's (1999) subsequent argument about creating high-skill ecosystems. The idea of skills ecosystems has been taken up in Scotland (Payne, 2008b) and is beginning to inform wider skill policy in the UK (Payne, 2012). The important feature of this approach is that it views skills shortages partly as a result of the strategies that employers use, rather than simply being a problem of supply. In practice, this approach does not contradict the thesis's approach, based on Foxon's definition, outlined above, as it simply needs technical change to be added to the ecosystem. Skill ecosystems represent another example of how skills policy is moving towards an evolutionary economic form of analysis. Examples of this wider view of skills policy include Keep and Mayhew's (2010) critique of the idea that skills supply is a social and economic panacea. Moreover, their subsequent argument that states skills policies need to be embedded in industrial strategies also argues for the need to address wider problems than just skills supply (Mayhew and Keep, 2014). Other work finds that skills and skill shortages coevolve with product strategies (Mason, 2004; Mason and Constable, 2011), where product strategies involve the adoption of new technologies and products. These ideas are important and will be used in the next sub-section. However, the concept of skills coevolving with technical change and institutions, as proposed in the thesis, produces the same empirical consequences and will, therefore, be the main approach used.

Nelson (1994) mentions skills as one of the institutions that co-evolve with technical change. Skills are seen as being linked to technical and organisational change (Piva et al., 2005). Similarly, skills can drive corporate R&D (Piva and Vivarelli, 2009). Equally, the skills and capabilities of a firm can coevolve with the firm's development (Levinthal and Myatt, 1994) and organisational change can be driven by skills (Caroli and Van Reenen, 2001). Institutions coevolve with economic behaviour (Van den Bergh and Stagl, 2003). Given the pattern of interrelationships and coevolution of skills, institutions and technical change shown by this literature the idea of them operating in a coevolving system seems plausible.

Underlying nearly all the evolutionary economic thinking is the realisation that economic actors cannot behave as rational agents due to bounded rationality (Simon 1955; 1959). This belief means that the skills that individuals and firms acquire are unlikely to be perfect matches for their requirements given the lack of perfect knowledge. The concept of coevolution suggests a perfectly adapted system. However, this does not have to be the case. Many coevolving systems, such as predator-prey or parasite-host systems, can be unstable and involve elements evolving at a faster pace than the others (Santos-Sacchi, 2008). There is also evidence that geographic variation may allow local equilibria while, at the global level, the pattern is much more complex and unstable (Thompson, 2005). Therefore, on the basis of these biological analogues (Porter, 2006) stability and synchronisation should not be expected in skill, institutions and technology systems. Indeed, complexity should be expected in these sorts of system (Lorenz, 2009).

3.4.3 Lagging sub-systems in co-evolution

The idea that skills coevolve with institutions and technical change is relatively uncontroversial. The idea that lagging sub-systems within this co-evolving system gives rise to problems is more novel. Therefore, this sub-section examines the literature on lagging sub-systems in coevolution for further insights.

The concept of co-evolution suggests that each of the sub-systems in a system move together in the same direction under the mutual influence of each sub-system, as well as the influence of external pressures. However, this thesis argues that when skills fail to evolve within a co-evolving system, involving institutions and technical change at the company level, skill shortages emerge. This argument implies that the presence of skill shortages will change the direction of the company, usually to the detriment of productivity or profitability. Given that the concept of co-evolution focuses on the idea of mutual interaction between the components of a system, there is surprisingly little literature on the concept of 'lags' or inertia within these systems. However, Carlotta Perez uses the idea of inertia within economic development.

> *"…there are mechanisms inherent in the way technologies diffuse which result in technological revolutions or changes of paradigm every 50 or 60 years, leading to long-term patterns of continuity and discontinuity in the techno-economic sphere which require matching transformations at the socio-institutional level. Yet inertial forces make the socio-institutional framework more resistant to change and rather slow to adapt to new conditions, except under critical pressure." (Perez, 2007: 218)*

Here, inertia is seen as creating imbalances, leading to a crisis. Similarly, the thesis further argues that inertia by the skills element of systems can lead to skills shortages and similar imbalances.as explained below.

The only example of previous research that examines the coevolution of skills, or human resources and ICT, is in a working paper by Paulo Seri. Seri argues that inertia caused by what he terms ‘behavioural lock-in’ leads to small Italian firms in ‘monotone’ industrial districts failing to acquire ICT skills and, hence, causes the firms, and the whole industrial district, to stagnate (Seri, 2005).

Another, parallel argument that emphasises the role of skills and their surrounding institutions come from the ‘varieties of capitalism’ tradition (Thelen, 2004). These varieties of capitalism relate to the different institutional paths and structures taken by various national capitalisms (Hall and Soskice, 2001). Thelen (2004) argues that in the UK, Germany, France, Japan and the US the role of skills and skills institutions developed differently early in the process of industrialisation, but in each case involved firms and unions, mediated by the state, reaching a settlement. Importantly, this settlement, and the particular national patterns of skills formation, have not been static but have continued to co-evolve over time.

Despite these alternative views, the linkage of skills shortages to lags by the skills component of a co-evolving skill, institutions and technical change system, used in this thesis, appears to offer a new approach. If lags or inertia on the part of skills institutions can produce shortages this also allows scope of policy interventions by addressing the lags. This insight hopefully allows the design of simpler and, hopefully, more effective, policy interventions.

3.4.4 How organisational routines can cause skill shortages

Organisational routines are a core concept of evolutionary economics and represent the practices or routines that organisations utilise in order to operate (Becker, 2004). They are the unit of selection, with successful routines being repeated and unsuccessful routines usually abandoned. They also allow basic corporate actions to be linked to more global economic activity.

As argued earlier and in more detail in Chapter 2, this thesis concentrates on the construction sector, which will be critical for the LCT. A critical feature of the sector is the degree of impact it faces from the business cycle. Indeed, there are arguments that the construction sector is the business cycle (Ghent and Owyang, 2010). Additionally, most work in the construction sector is based on projects which, in turn, are also largely won through competitive bidding. This uncertainty creates a very fragmented industry structure, with many small sub-contractors and sole traders interacting in a complex manner. Again, the evidence for this is provided in Chapter 2. This fragmentation, as a result of organisational routines, provides a very flexible workforce for the main contractors, who employ sub-contractors, as and when required. It also encourages specialisation amongst sub-contractors, as they know that there is a greater probability that specialist skills will be utilised more of the time than if they operated as a general builder.

These advantages create and reinforce the fragmented structure of the sector, as a result of the organisational routines adopted by economic actors within, and around, the sector. The established organisational routines (Nelson) within construction means that Individual employers seek to make their employees sub-contractors, as this means that they have greater flexibility and only have to pay the former employees when there is work. This flexibility means that especially when there is a downturn in construction activity, sub-contracting increases. However, during an upturn in activity, and the associated skills shortages, there is a greater tendency to retain staff and keep them on the books to ensure access to the skills. However, the tax advantage for individuals, and employers, of sub-contractors means that the pressure is generally in favour of fragmentation (Briscoe et al., 2000).

Furthermore, the fragmented structure of the sector depresses skills training (Forde and Mackenzie, 2004; Forde et al., 2009) as employers believe that once an employee has been trained they will leave to set up on their own. This fear also deters small employers from taking on apprentices (Hogarth and Gambin, 2014). Equally, employers' previous experiences drive their response to Government skills initiatives (MacKenzie et al., 2000). Finally, the impact of the business cycle means that what training is undertaken by the sector is largely abandoned during the down-turn in activity. All these organisational routines detrimentally impact on skills training and supply.

Although, organisational routines, by definition, operate at the level of firm collectively they can have a sector-wide impact as long as sufficient numbers use the same, or similar, routines. Importantly, although the routines may be rational for individual firms they can have a negative impact collectively in a process akin to the 'tragedy of the commons' (Ostrom, 2008).

Chapter 2 of the thesis goes into more detail about how the business cycles and the construction industry business structure, impact on training and innovation (Sheffer and Levitt, 2010) in the construction sector. Additionally, Chapter 2 further explores the routines that construction employers and employees deploy as a result of the business cycle and industry structure.

3.5 Skills institutions and skills governance

The UK state provides an overarching governance function for skills formation, as well as the main source of funding for teaching and training institutions. This governance is further mediated by a series of governance institutions. Therefore, the role of these varied institutions becomes critical in terms of understanding the skills requirements of the LCT. These skills governance institutions will lead any policy interventions by the State. The section consists of three sub-sections:

- Skills and the State
- Skills governance institutions, and
- Predicting skills shortages.

These issues are covered in turn below.

3.5.1 Skills and the state

To a degree, the role of the state in skills formation, or education and training, has been accepted. However, the policy literature (Roberts, 2002) and employers (Aldersgate Group, 2010) often put more emphasis on the role of skills in innovation and the LCT than the academic literature surrounding these issues.

Despite the acceptance of the role of the State in education and training policy, the pattern of skills governance in the UK is highly contested (Keep, 2006). The nature and pattern of delivery of vocational qualifications are disputed and has been subject to many changes in the UK (Fuller and Unwin, 2011). Likewise, the balance of emphasis in vocational education has swung between apprenticeships and college-based training (Anderson, 2014). The pattern and importance of vocational education vary considerably between countries and represents a distinctive aspect of national education systems (Lerman, 2013). Perhaps, reflecting this contestation, it is clear that often education and skills policy is not firmly rooted in research evidence (Hillage et al., 1998). Rather, it seems that the skills system has been subject to ideological and political interference (Keep, 2006).

Reflecting the view that innovation is currently biased towards higher level skills, much of the UK policy effort on skills and innovation has been concentrated at this level (Roberts, 2002). This concentration is despite the emphasis on the intermediate level regarding broader training qualifications in the construction sector. This disparity is largely a result of the academic autonomy maintained by universities in the UK, which minimises the scope for policy intervention. However, it also reflects an R&D centred view of innovation rather than on absorptive capacity and innovation adoption (Cohen and Levinthal, 1989).

There has been a long history of shifting biases between education and technology (Goldin and Katz, 2008). Equally, there is growing evidence that the bias towards high-level skills may be working itself out (Beaudry et al., 2013). This suggests that the policy focus probably should be returning towards intermediate or vocational, level skills (Toner, 2010). However, the UK's government sanctioned, employer-led skills policy, and a market liberal approach to skills, may make any transition to greener vocational skills problematic (Evans and Stroud, 2014). Despite the rhetoric, it is often difficult to engage employers in the process, leaving a system that is often led by a minority of employers (Mazenod, 2014). Despite this, employer-led training, processes are attractive to other countries (Lerman, 2013) and this bottom-up approach to skills has many benefits (Froy, 2013). This topic of employer-led policy formulation, since potentially problematic if the demands of the LCT are to be met, is returned to in the concluding section of this chapter, and again in Chapter 6 in the context of a discussion of skills institutions. The governance issues surrounding low-carbon skills and their forecasting are also dealt with in more detail in Chapter 6 of the thesis.

3.5.2 Predicting skill shortages

Predicting skills shortages is key to the success of the LCT, as this will enable actions to mitigate the risks inherent in critical skills shortages. Predicting skill shortages, or more usually, predicting future skills demand and supply, is one of the core roles for the skills governance and skills institutions system. This allows the skills governance system to prioritise new skills, develop appropriate qualifications and guide learners and students in the direction that institutional and technical change that is driving the system.

However, predicting skill shortages is difficult. This is because there needs to be an underlying economic forecast that usually occurs at the sectoral level. There then needs to be a forecast of future occupational change, based on the economic forecast and, usually, historic occupational change at the sectoral level. The occupational forecast is then translated into a skill forecast and is often matched to changes in projected education and training patterns (Econ Pöyry, 2008). All of these steps in this standard method of predicting skill shortages introduce uncertainty to the process and limit the time horizons that can be plausibly forecast. Despite these problems, this quantitative method of predicting skills shortages has often been attempted, as avoiding skill shortages is seen as an important function of funders of education and training systems (Veneri, 1999). Sometimes, for short term forecasts the alternative approach of using 'Delphi forecasting' techniques have been used to examine future skills shortages (Milkovich et al., 2011). Delphi forecasting is a qualitative technique used to elicit the views of key informants which are then averaged and the results fed back to them for validation. Since the Delphi technique is qualitative and uses a large group of experts in the sector it can be useful in that it helps to create the future by setting expected norms (Rowe and Wright, 1999).

The main problem when endeavouring to forecast potential skills shortages that could disrupt the LCT, is that the construction sector is heavily impacted by the business cycle and it is, perhaps, the timing and extent of business cycles that the current economic forecast models have the most problems with. Since the focus for the LCT is on the skill requirements of the construction sector, this is problematic, as currently a plausible economic forecast is only available for a few years while the requirement is for forecasts to 2050. To address the need for a longer-term skills forecast, the approach that is adopted in Chapter 4 is to predict the underlying growth rates, firstly based on demographic and educational attainment information.

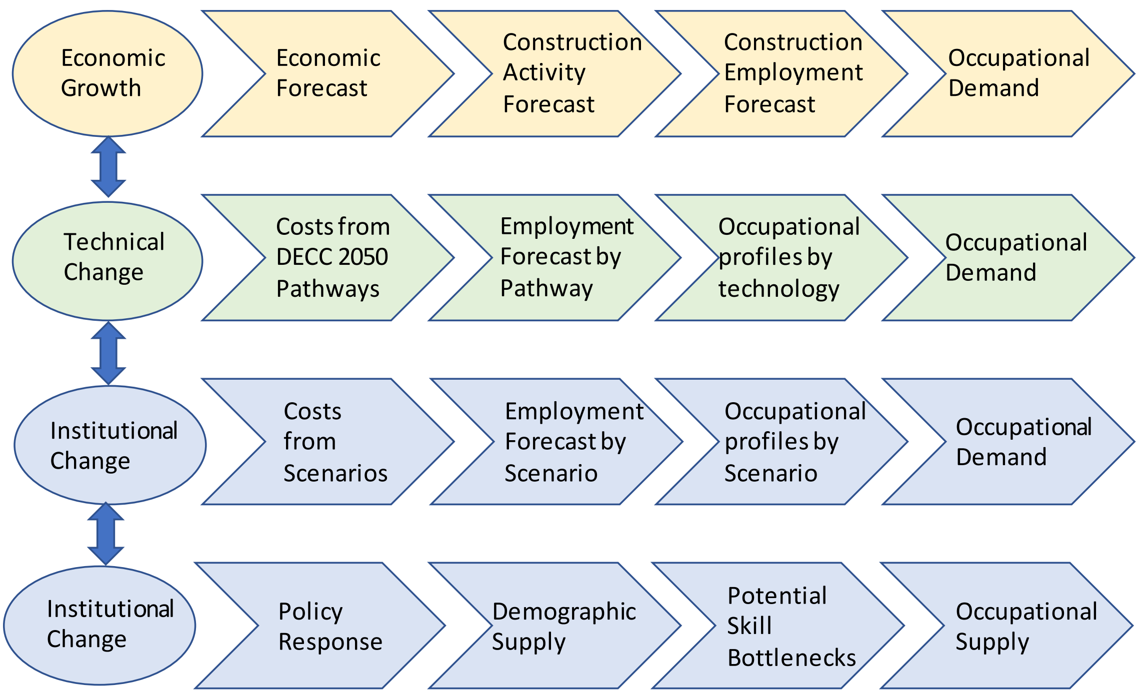
Predicting skill bottlenecks is potentially more important to the success of the LCT. With current forecasting models, this is only feasible over a period of about ten years. The concept of bottlenecks will be explored in more detail in Chapter 5. However, the concept is relatively simple. It refers to skills shortages that become persistent, mainly due to requirements for long training and experience, combined with increased demand due to technical change. These skill bottlenecks are, therefore, more potentially serious than simpler skill shortages. New models to identify bottlenecks are needed, as the traditional approaches to predicting skills shortages are less capable of identifying the skills bottlenecks. This means that devising a forecast to predict potential skills bottlenecks and developing mechanisms to address them are important for the success of the LCT to 2050 and beyond. The difficulty is collecting sufficient data at the disaggregated level from employer reports, or other sources, that identifies skills shortages over periods of more than one year. Therefore, a method using Labour Force Survey based size of occupations and the required duration of occupation specific training is developed in Chapter 5 to identify those occupations potentially at risk of producing bottlenecks over the longer-term. This innovative approach should provide a more accurate method of forecasting skills shortages over the long-term of the LCT. This contrasts with the short-term forecasting supply and demand at the occupational level.

3.6 Summary and Implications for the Thesis

The preceding sections have, hopefully, provided a theoretical understanding of skills and shown that skills need to co-evolve alongside technical change, with different types and levels of skills required at different phases of the product cycle and innovation cycle. It has also proposed a Tripartite Model to explain the co-evolution and interaction between underlying evolving systems driving growth in construction, technical change and institutional change. This model is developed in order to better forecast the skills demand necessary to ensure the success of the LCT and, importantly, to identify any potentially disruptive skills shortages or bottle-necks.

Importantly, the tripartite model is more than a descriptive model it is used as the basis for developing a quantitative model of the pattern of occupational supply and demand over the period of the LCT. Figure 3.1 illustrates the sequence of processes involved in producing forecasts of occupational demand and occupational supply. The economic growth leg of the tripartite model moves from an evolutionary economic model of the next fifty years, via a construction activity forecast to an employment forecast and subsequently a forecast of occupational demand due to economic growth. Similarly, the technical change leg builds on the costs from the DECC 2050 pathways to produce forecasts of employment, taking into account forecast productivity growth to then allow occupational demand due to technical change to be forecast on the basis of the occupational profiles of contractors associated with each pathways technology. The impact of institutional change in analysed in terms of both the additional occupational demand created by various policy driven scenarios and also the occupational supply generated by policy responses and the pattern of demographic supply taking into account potential bottlenecks.

Figure 3.1: The Three Evolving Systems Co-evolving to Produce Occupational Forecasts



The following chapter, Chapter 4, examines the impact of economic growth over the period of the LCT on future construction sector occupational demand. This is achieved by developing a novel evolutionary economic forecast which is then used to produce a forecast of construction activity. Next the forecast of construction activity is used to produce a forecast of construction employment and then a forecast of occupational demand.

Chapter 5 uses the cost forecasts from the DECC 2050 pathways to produce construction sector additional employment forecasts by four of the pathways. Then using occupational profiles for each of the pathway technologies the pattern of additional occupational demand as a result of technical change is forecast.

Chapter 6 has two main purposes, firstly it produces patterns of occupational demand resulting from scenarios of adaptation activity in response to rising sea-levels and flooding due to increased rainfall as well as the option of building sufficient dwellings to meet the pattern of demand. Secondly, the chapter also examines the institutional drivers of supply of appropriately trained people to meet the expected pattern of demand. Finally, Chapter 7 draws together the various strands from the preceding chapters and makes a number of policy recommendations.

4 - Forecasting Construction Activity

4.1 Introduction

This introduction provides the aims of the chapter and an outline of the methodology used. It also puts the aims of the chapter into the context of the overall thesis and finally outlines the structure of the rest of the chapter.

4.1.1 Aims

This chapter aims to produce a core forecast of construction activity in the UK, based on historical data, to underpin later chapters. The forecast produced will then provide the first component of the tripartite model developed in Chapter 3 to address the interacting and co-evolving factors that determine skills demand.

4.1.2 Methodological outline

To achieve these aims, the chapter seeks to provide a rationale for the use of a new economic forecasting methodology that is applied here. This will, for the first time, enable a long-term prediction of the trends underlying UK construction activity.

The forecasting process adopted here involves generating a plausible, long-term general economic forecast that incorporates both GDP trend forecast and the impact of the business cycle. This forecast is then compared to other long-term forecasts for the UK economy. Next, the chapter translates the economic forecast into a core long term forecast for both construction activity and numbers of construction workers. This core forecast provides long term data on overall construction activity in the UK, before the additional demands of the low-carbon technical options and low-carbon policy developments are added to enrich the forecasts in later chapters. The chapter concludes with a discussion of the implications for low-carbon skills, based on the findings of this core forecast.

4.1.3 Context

The Tripartite Model developed in Chapter 3 argues that three factors combine to determine skills demand. The model consists of three interacting and co-evolving components. These three components are: core activity growth, growth due to technical change and growth due to institutional or policy changes. This chapter provides a long-term construction employment demand forecast. As such, this chapter provides the first leg of the Tripartite model, long-term growth in construction employment demand.

This forecast is then used to provide a baseline for the later scenarios of technical change and institutional change that also impact on the Low-Carbon Transition (LCT), as discussed in Chapter 3. Chapter 5 deals with the additional impacts of technical change and Chapter 6 deals with the impacts of institutional and policy changes.

4.1.4 Structure of the chapter

The chapter consists of a further three sections covering, in turn, the following topics:

1) Background and methodology – section 4.2

This section examines existing construction sector forecasting methods and their limitations. It then introduces the use of forecasts to produce long-term predictions in the context of the LCT. Next, the subsection introduces 'Multi-Channel Singular Spectral Analysis (MSSA)'. This technique allows long-term forecasts consistent with many evolutionary economic growth models. The section then discusses how the long-term economic forecast generated using MSSA will be translated into construction activity and labour demand forecasts. The following stages apply the methodology and will be outlined here.

2) MSSA Based Long-Term Economic Forecast - section 4.3

This section uses 'Multichannel Singular Spectrum Analysis' to produce an economic forecast of underlying GDP growth and investment, including future business cycles. The variables examined, and included in the later forecasting, are Real GDP, Investment, Productivity, Working Age Population and Tertiary Level Attainment of the working age population. This forecast uses the historic trends from above, and the interactions between the data series, to produce a forecast consistent with many evolutionary economic ideas of economic growth.

3) Forecasting Construction Activity based on the Economic Forecast – section 4.4

This section uses the economic forecast from section 4.3 to produce a core forecast of long-term underlying construction activity. This linkage is based on analysis of the historical relationship between construction and the overall economy. The construction forecast is then used to produce a forecast of construction employment and future construction occupational structure. This section also introduces how the core construction forecast will be used to inform the later chapters.

4.2 Background and methodology

This section provides a theoretical background for the later analyses. It firstly examines the existing methods that are used to forecast construction activity and the limitations of these methods for looking at low-carbon skills, which require longer than usual time-horizons.

4.2.1 Existing construction forecasting methods

One of the main problems with existing methods for forecasting construction skills requirements is that they are only capable of forecasting short-term while, as explained in Chapter 2, the LCT requires forecasts to at least 2050. Many econometric methods have been used in forecasting construction activity. These methods include Auto-Regressive techniques (Hua and Pin, 2000; Ng et al., 2011), Vector Error Correction Models (Jiang and Liu, 2011; Fan et al., 2011), Genetic Algorithms (Ng et al, 2008), Multiplier Models (Sing et al., 2012), and a mixed approach (Wong et al., 2011). However, these methods are only able to forecast up to about five or ten years with any reliability. Therefore, these methods do not help with the longer-term requirements of forecasting over the LCT.

If some of the existing academic forecasts of construction activity in the UK are now examined in more detail, these usually start with a general economic forecast. These underlying economic forecasts are limited in the period over which they can reliably forecast (Akintoye and Skitmore, 1994; Agapiou et al., 1995; Ejohwomu et al., 2006). There are also a range of commercial UK construction sector forecasts. For example, Experian and Construction Skills (2010) produce a series of forecasts of construction employment and skills demand. These forecasts use econometric models of future economic activity and, in particular, construction activity. Experian's forecasts also involve forecasts of business cycles, as these particularly impact the construction sector (Kydland et al., 2012). However, their longest forecast only covers a period of 15 years (Harty et al., 2007), which is insufficient for understanding the dynamics of the LCT, extending to 2050 and beyond (Foxon et al., 2010). Other commercial forecasts of construction activity (Hewes & Associates, 2010; CPA, 2015) tend to have even shorter time-horizons. These commercial studies use aggregated short-term forecasts or assessments by professionals. For instance, the Royal Institution of Chartered Surveyors produces a regular forecast of upcoming activity based on reports of surveyors (Hanley, 2014). The Construction Products Association produces a similar series of forecasts (CPA, 2015) based on their members' current output. This again means that current practice in the UK does not operate at the time horizons required for studying the LCT.

The problem is that most of these techniques only reliably forecast for relatively short periods of time and tend to become unreliable beyond the usually cited periods because of their underlying assumptions and the nature of the techniques used (Elliott and Timmermann, 2008).

These various problems, affecting both the reliability and validity of existing construction activity forecasting methods, mean that other techniques need to be used to explore the long-term dynamics of the construction sector and which this thesis seeks to develop. The next subsection outlines the proposed forecasting approach which is used later in this chapter and further chapters to address these problems.

4.2.2 Business cycle and construction forecasts

An example of the use of scenarios for the LCT is given by the GDP scenarios underlying a series of climate change socioeconomic pathways by O'Neill et al., (2015). These have a similar purpose to the proposed scenario in this thesis, in that they are designed to identify more clearly potential economic problems for the LCT. The focus is on the scale of investment required for addressing climate change and the economic consequences if the mitigation and adaption measures are not sufficient.

Furthermore, the O'Neill et al. scenarios underlying 'socioeconomic pathways' are also based on long-term trends, in particular, a shared set of population scenarios (KC and Lutz, 2014) similar to the approach adopted by the thesis. However, in contrast to the methodology adopted here, although the O' Neill et al. scenarios sought to examine long-term trends, no effort was made to identify and project business and other cycles (Leimbach et al., 2015). The scenarios also produce a wide range of GDP forecasts which limit their use as a forecast to underlie construction growth. The absence of business cycles is not a problem for these socioeconomic pathways, as they concentrate on long-term trends rather than the dynamics of the business cycles. However, this is problematic when forecasting low-carbon skills, given the impact of the business cycle on the construction sector, which is key to the success of the LCT, as identified in Chapter 2. In particular, the business cycle impacts on the construction workforce. This is clearly shown in historical data with, for example, construction employment dropping by 30 percent from the pre-crisis peak in 2007 to 2010. Hence, the business cycle needs to be included in any forecast of construction skills. Therefore, the methodology of the thesis adopts a core forecast that includes business cycles and then further scenarios build on this core scenario.

However, the main problem with this approach is that it generates a series of scenarios which between them cover all possible futures. This is useful for exploring the drivers of future change, but introduces too much complexity when examining the consequences of future change. As Wilkinson says: "Scenario practices are under-researched and under-theorised. The potential strengths, and limits, of scenario practices which encompass probable, plausible or possible futures thinking are unclear" (Wilkinson, 2009: 112). This problem needs to be addressed if a useful forecast is going to be produced.

4.2.3 Singular spectral analysis

This subsection explains why Singular Spectral Analysis has been selected as a suitable method to analyse long-term trends and to forecast economic growth over the long-term to overcome some of the problems with the existing methods outlined in subsections 4.2.1 and 4.2.2 above.

Singular Spectral Analysis (SSA) involves the spectral decomposition of time series, or random fields, into trends, cyclic components and white noise (Vautard et al., 1992). SSA is derived, in part, from Fourier analysis of trends (Bloomfield, 2000; Bozzo et al., 2010) and spectral analysis from signal processing (Marple, 1987). The approach is to break down the time series into any detectable regular components and then reconstruct the time-series with the aim to minimise any remaining randomness or white-noise.

Initially, the method was used to extract seasonal (Nerlove, 1964) or business cycle patterns (Granger, 1966) in time-series. However, increasingly the method has been shown to also be more effective in forecasting economic trends than ARIMA and regression-based techniques (Hassani et al., 2013; Silva and Hassani, 2015). This superior forecasting ability is partly due to SSA not needing any assumptions about normality or parameterisation (Golyandina and Zhigljavsky, 2013).

Since SSA has no required prior assumptions, it is particularly useful for analysing and forecasting over long-time frames. This has led to the widespread use of the technique in climatology (Jevrejeva and Moore, 2001), meteorology (Fraedrich, 1986), geophysics (Kondrashov and Ghil, 2006), forecasting mortality (Mahmoudvand et al., 2013) and marine science (Colebrook, 1978), some of which forecast over millennia. Ghil et al., (2002) provide a useful review of the SSA approach, with a particular reference to analysing climatic time series, underlining its suitability and reliability for analysing and forecasting complex time series such as those associated with LCT.

This established use of the Singular Spectral Analysis in these areas represents another factor behind SSA's adoption in this thesis, which requires a forecast that extends to 2050 and beyond.

Furthermore, there is a long history of the use of spectral analysis in econometrics including a Rand Corporation report for the US Department of Commerce (Cooper, 1972) and a monograph dealing with the technique (Fishman, 1969). However, the more recent development of Singular Spectral Analysis (SSA) is that it has recently been used to analyse economic time series (Hassani et al., 2009). Indeed, the use of SSA in economic and financial time series analysis is growing (Hassani and Thomakos, 2010). In particular, it has been applied to the forecasting of European industrial production (Hassani et al., 2009) and UK industrial production (Hassani et al., 2013). Additionally, Kapl and Müller (2010) show that SSA forecasts steel prices more effectively than regression based techniques.

However, despite the theoretical suitability of SSA for the required analysis here, there is a limited literature covering the use of SSA for examining long-term economic growth and associated business cycles (Iacobucci, 2003). There appear to be only three papers using SSA: a 2010 paper by Sella et al., a 2012 paper by de Carvalho et al., and another 2015 paper by Groth et al.covering the US. These have only analysed relatively short GDP time series and have not attempted to forecast GDP. However, the results are promising and this means that, despite breaking new ground, SSA is still thought to provide the most appropriate solution to the requirements of the thesis for forecasting economic growth and construction activity over the longer-term.

4.2.4 Multi-channel singular spectral analysis

At an early stage, it was realised that spectral analysis could be used to examine the relationships between variables using cross-spectral methods (Granger, 1969). However, Multi-channel Singular Spectral Analysis (MSSA) is a more recent development that uses a methodology largely developed in St Petersburg (Polukoshko and Hofmanis, 2009). MSSA is an extension of SSA, which allows the simultaneous analysis and forecasting of multiple time-series and examines the interactions of the principal components of each series and the partial correlations between them (Golyandina et al., 2014). This is deemed more suitable for forecasting, as MSSA allows multiple variables to be forecast together, taking into account their interactions (Kapl and Müller, 2010). Importantly, this method also allows the influence of known variables, such as working age population, to be used to help predict other variables.

Despite using the interactions between variables, since there are no assumptions of causal relationships, nor any explicit model of the relationships between the series, the results are based solely on the historic relationships between the variables and their trends. Another way of conceiving of the process is that MSSA provides a mathematical expression of the co-evolution of various variables.

This lack of causality means that the inclusion of other data series could produce different results. However, if the method cannot find a historical relationship the new variable will not influence the forecast. Therefore, the resulting forecast needs to be seen as a forecast based on the included data rather than an econometric prediction. However, despite these cautions, other forecasts of economic data using this method have proven to be accurate.

4.2.5 Rationale for approach

Analysis of historical trends can inform the likely pattern of future development. This section examines critical variables that are available in long time-series that will also be important in determining the future economic developments which will impact on the success of the LCT. To forecast over the 50-year period necessary for the LCT, it is necessary to base the forecast on a much longer time-series to ensure reliability. The established method is to employ a base three times longer than the required forecast period. Therefore, the data analysed here stretches from 1856 to 2064.

In addition, it is known that GDP growth and investment levels are important predictors of construction sector activity (Tse and Ganesan, 1997). This role for GDP means that any forecast of UK construction activity needs to start from a forecast of underlying GDP growth. Given the importance of the business cycle for construction activity, as detailed in Chapter 2, any forecast of GDP needs to forecast the underlying trend and any cyclic patterns that superimpose on the trend.

Singular Spectrum Analysis (Vautard et al., 1992) and, in particular, the R package 'Rssa' allows this dual approach to forecasting (Golyandina and Korobeynikov, 2014) and has therefore, been selected for use here. Section 4.3 details the application of Singular Spectrum Analysis and Multi-Channel Singular Spectrum Analysis to the problem of forecasting UK GDP growth.

4.3 Producing a long-term economic forecast

The next step of the forecasting process aims to identify the cyclic and endogenous nature of the business cycle.

4.3.1 Available data

The historic data used by the forecast largely comes from the Bank of England's Three Centuries of Data (Hills et al., 2010). This source provides time series covering Gross Domestic Product

(GDP), Gross Fixed Capital Formation (GFCF) and productivity. A time series covering working age population was developed from historic census data, Office of National Statistics (ONS) data and Eurostat population projections and; where necessary, missing data was interpolated using the csipolate Stata function. The Eurostat population projections that underlie the forecast working-age projections come from their central high migration scenario. Finally, a series detailing the percentage of the working age population with a tertiary qualification was taken from the Barro and Lee (2015) database, with some extension of the data backwards and forwards as well as interpolation using the Stata csipolate function. The GDP, GFCF and productivity data runs from 1856 to 2014 and the working age and educational attainment data runs from 1856 to 2064.

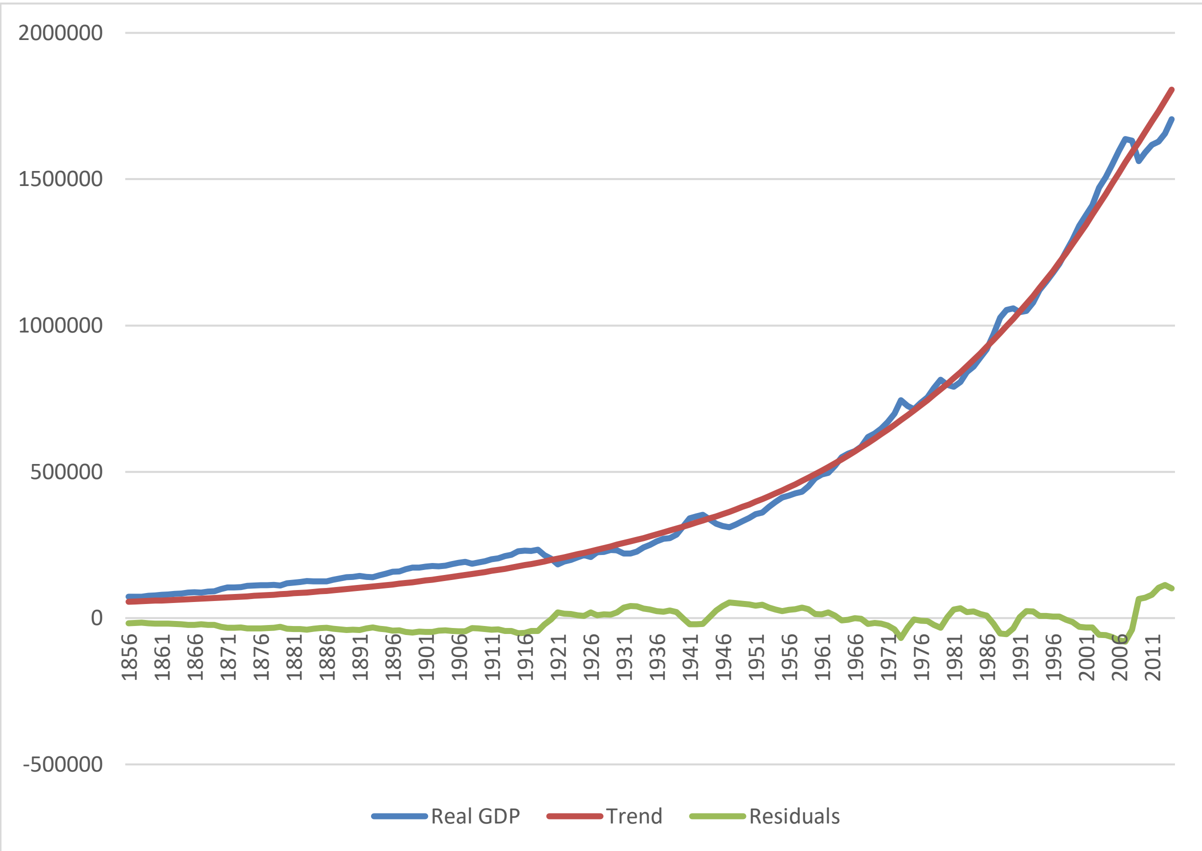
The data has been selected as GDP, GFCF, productivity, and working age population were classically used by Solow (1956) to explain GDP growth. Similarly, GFCF, working age population and productivity were used by Nelson and Winter (1982) to simulate GDP growth using an evolutionary model developed by Nelson et al (1975). The addition of the percentage of working-age population with tertiary level qualifications is a measure of labour quality. This follows work by Barro and Lee (2015) which shows the importance of this type of human capital variable for explaining GDP growth.

4.3.2 Long-term trend in GDP

The RSSA package uses the ‘Caterpillar’ algorithm that reduces the calculations required by only examining the data through a moving window (Golyandina and Osipov, 2007). The algorithm aims to find the trend and cyclic patterns that minimises the white noise, or randomness, within the time series. The trend and any cyclic components are then used to reconstruct the series. This reconstruction of the data series allows the underlying trend in UK Real GDP to be derived and the resultant residuals produced. Since the objective is to obtain the long-term trend, a long window of 75 years is used. This length of window means that any business cycle component is smoothed out from the trend.

The initial analysis examines the historic pattern of GDP growth in the UK, in particular the underlying trend and the deviations from the trend. These results of the analysis are shown in Figure 4.1 which illustrates this data generated using the SSA function within the R software package. The chart shows a pattern of continuous trend growth in the UK's GDP The graph also shows that there have been periods of above and below trend growth, as shown in the residuals. Although, the recent recession appears to have been a serious digression from the trend.

Figure 4.1: Real GDP series, trend and residuals



Source: SSA analysis

An understanding of the business cycles is critical for any long-term forecast of the construction sector. Here it is the residuals from the long-term trend which make the cycles more visible. Visual inspection of the residuals in Figure 4.1 suggests that the upswings are more variable in length than the downswings. They are also more gradual and longer than the more dramatic and shorter downswings. These results show a 'saw-tooth' pattern which is well known (Morley and Piger, 2012).

Evolutionary economic models, in line with the thesis (Chapter 2) view the business cycle as endogenous and resulting from internal contradictions in the economy (Dosi et al., 2006), for example, the development of skills shortages reducing output. Therefore, since the SSA method allows the cycles to be viewed as endogenous, and not necessarily the result of external perturbations, it provides the best method for the intended longer term LCT forecast which is to be generated.

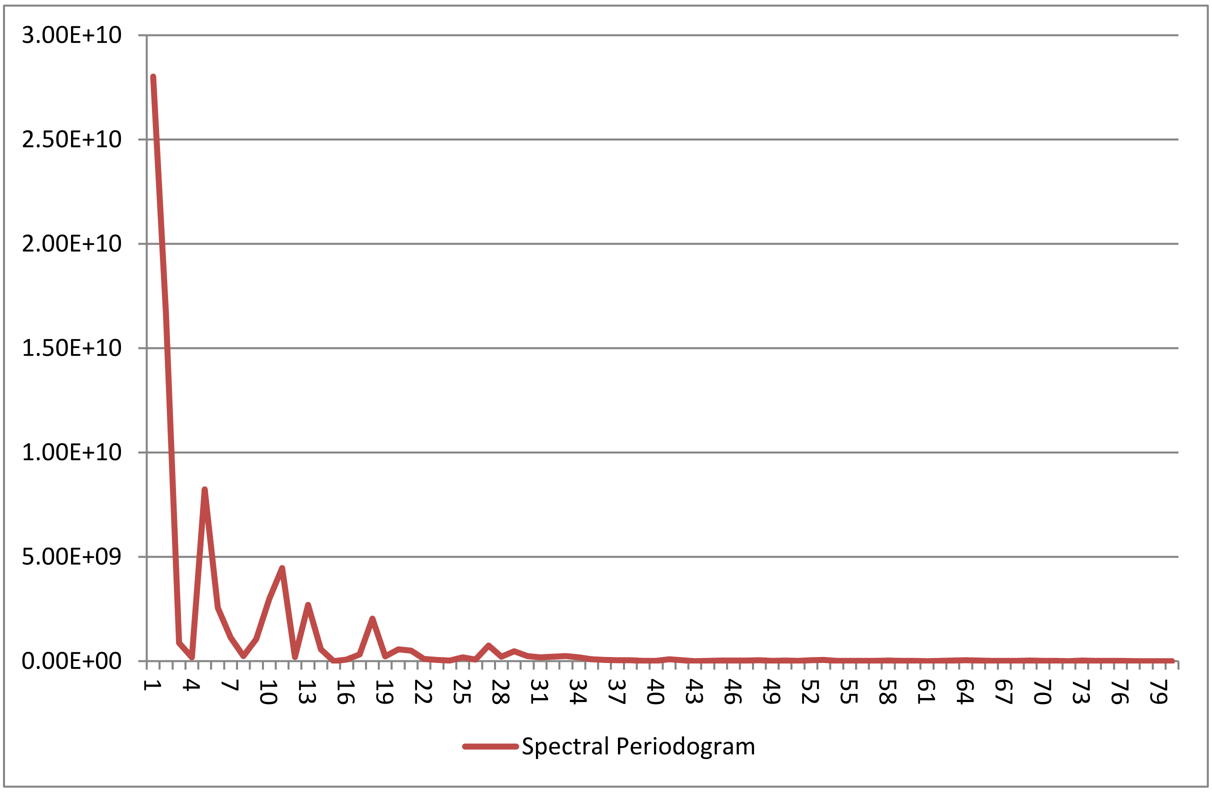
Having established the long-term GDP trend, the same data set was then analysed to determine the length of the business cycles and to any determine cyclic patterns.

4.3.3 Determining cyclic patterns

As part of the process of decomposing the original time-series, the SSA method identifies any underlying cyclic patterns. These cyclic patterns are then added to the reconstructed series. The standard approach to examine the cyclic patterns when applying SSA is to produce a spectral density periodogram. A problem with business cycle data is that the normal diagnostics for cyclic patterns are designed to work with symmetrical sine waves rather than the saw-tooth pattern visually apparent in Figure 4.1. This asymmetry makes the interpretation of traditional spectral density periodogram less transparent than with some other types of data series.

Figure 4.2 provides the spectral density periodogram based on the residuals from the preceding SSA analysis. The graph suggests that there is a pronounced five-year periodicity, with weaker peaks at eleven, thirteen and eighteen years, as well as the suggestion of a further peak at 27 years. Five years is a shorter period than the commonly accepted length of business cycles. However, using SSA, a similar five-year pattern has been discovered in the US data by Groth et al. (2015) which appears to support the results here. Likewise, a 5.6-year periodicity was found in a shorter quarterly series of UK data (Sella et al., 2010), which seems to futher support the results generated here. The suggested explanation for this apparent five-year cycle is that this is picking up the signal from the regular downswings of recessions, while the more irregular upswings are shown by the eleven and thirteen year peaks (Groth et al., 2015).

Figure 4.2: Real GDP spectral density periodogram



Source: R spec.pgram function on residuals

It is also suggested that the longer Kontratieff waves are similarly asymmetric and have downswings of about 27 years (Coccia, 2010), as detected in the spectral density shown in Figure 4.2.

Using the cyclic information from the preceding spectral analysis, it is now possible to modify the long-term GDP trend forecast into a more plausible forecast that includes business and other cycles.

4.3.4 MSSA based forecast of economic variables

This next step of the methodology uses an extension of SSA termed Multichannel Singular Spectral Analysis (MSSA). This is a useful technique, since MSSA not only looks at the trends and cyclic behaviour of the individual time series, but also takes account of the interactions between the series by examining the partial correlations between them. The ability of the technique to explore these interactions means that by employing MSSA it can produce a co-evolving forecast based on the variables included in the analysis.

Given that MSSA, like SSA, is non-parametric and the results are dependent on the relative units used for each time series, standard practice is to normalise the series to allow each series to have an equal impact on the forecast pattern. Additionally, since the thesis objective is to forecast both the long-term trend, as well as the shorter cyclic periodicity of the business cycle, a shorter window of ten years is used. The shorter window allows the pattern of the business cycle to be picked up and shown in the forecast.

MSSA has several approaches to forecasting, the two most notable being recurrent MSSA and vector MSSA. Since Rosmalawati et al. (2014) indicate that Recurrent MSSA forecasting is more reliable with economic time series than vector MSSA forecasting, it is the method adopted here. The advantages are that recurrent MSSA forecast methodology only uses trends, cyclic patterns and the historic relationship between the series. This reflects the evolutionary economic model proposed in Chapter 3. In addition, by using the longer working age population and educational attainment time-series allows the forecast to incorporate the impact of the demographic transition with lower birthrates and longer lives as well as the impact of plateauing educational attainment.

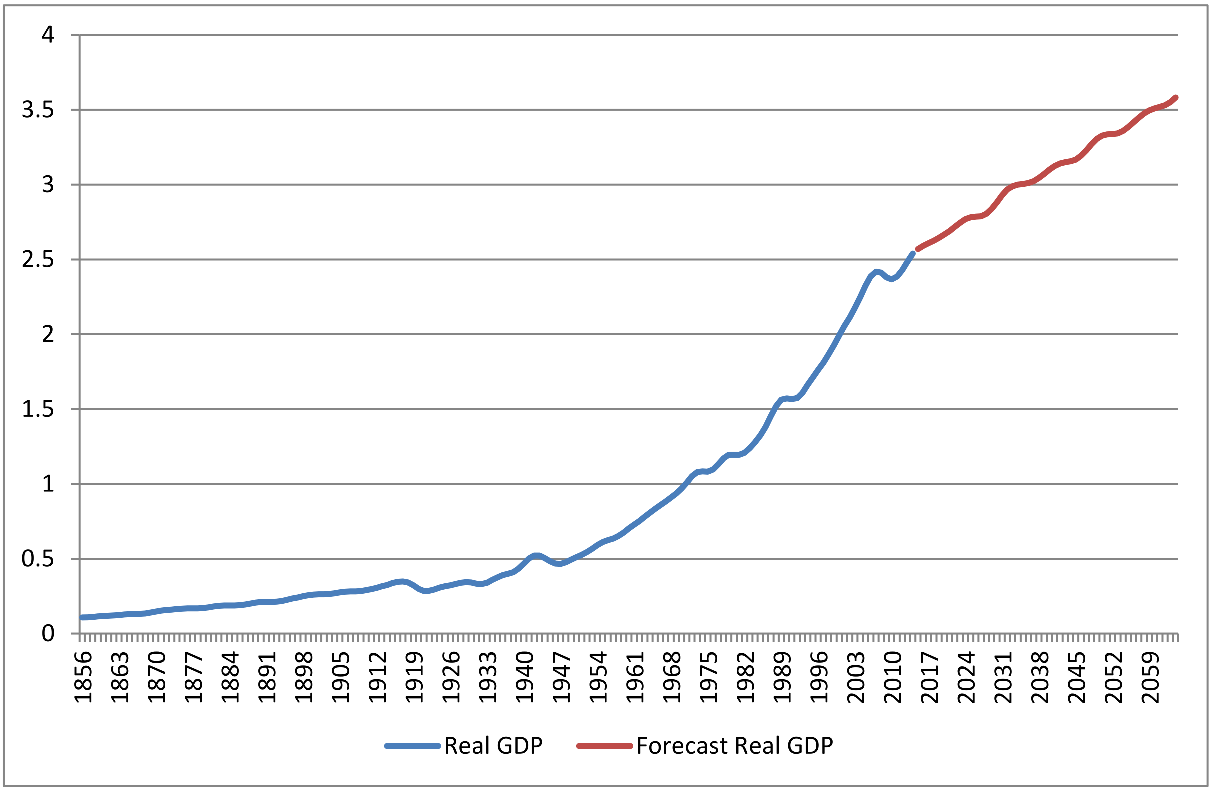
Results

This MSSA forecast here incorporates real GDP, real investment and per capita productivity from 1856 to 2014, along with working age population and the proportion of those of working age with tertiary level qualifications for 1856 to 2064. The two longer series, the working age population and the tertiary level qualified, are essentially used as predictor variables for the forecasts of the remaining variables. This means that the known changing future pattern of working age population and educational attainment is used to influence the forecast pattern of GDP, GFCF and productivity growth. It also reflects the concerns that declining population growth and plateauing educational attainment will reduce long-run GDP growth (Reher, 2011). These concerns about the impact of demographic change underlies the increasing use of human capital and demographic models for long-term economic forecasts (Crespo-Cuaresma, 2015).

The MSSA method allows the degree of smoothing of trend and forecast curves to be determined by the size of a 'window' on the series. To reflect the cyclic patterns detected in the time-series shown in Figure 4.2 the analysis uses a shorter window of 10 years. This short window is advantageous, as it allows cycles of the length of business cycles to emerge in the forecasts, but it requires greater computational effort. The results of the MSSA analysis are shown in Figures 4.3 and 4.4

Figure 4.3 shows real GDP without inflation from 1856 – 2014 and then the MSSA forecast to 2064. Interestingly, the graph suggests that the forecast GDP will grow at a slower rate than the last 50 years. This has implications for the UK's ability to finance new low carbon technologies and infrastructure. This will be discussed further in Chapter 6.

Figure 4.3: Historic Real GDP and MSSA Forecasted Real GDP



Source: MSSA Forecast

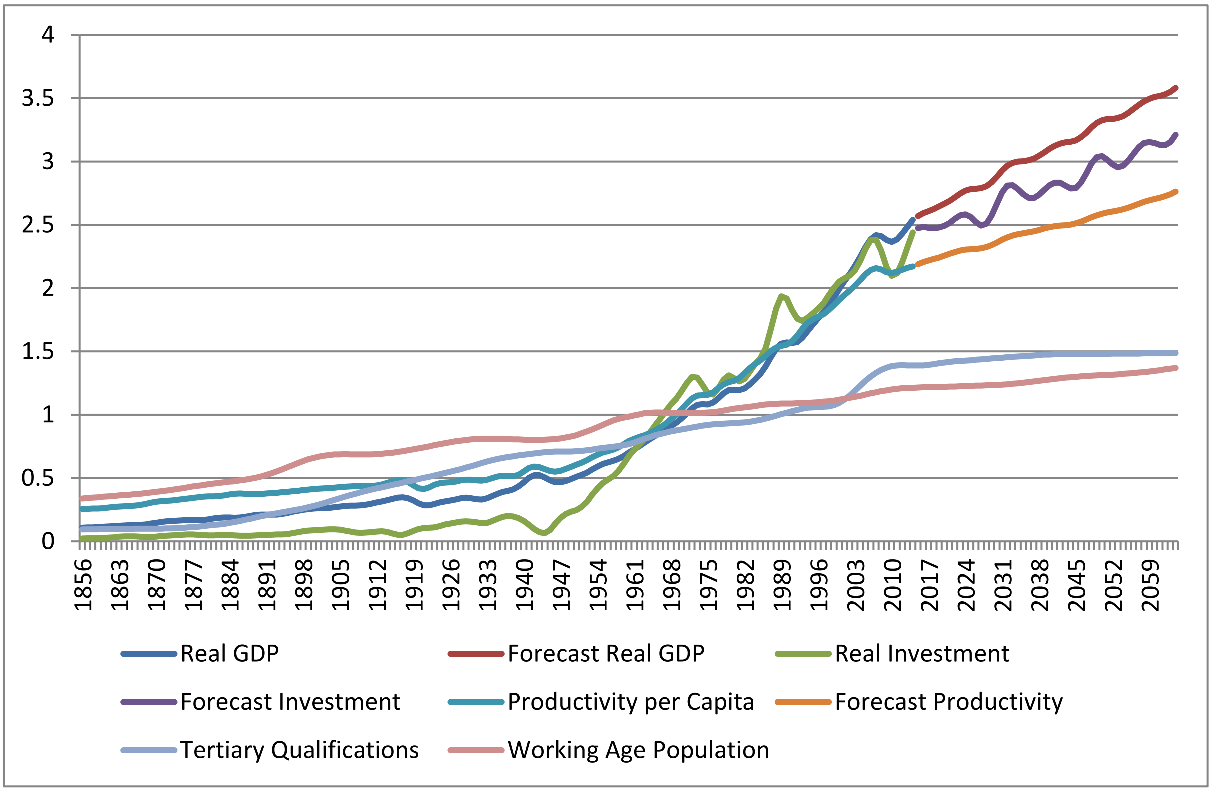
Using the MSSA package, Figure 4.4 illustrates the forecast UK real GDP and also shows the underlying drivers of this growth i.e., investment and productivity. The vertical axis has been normalised using root mean squared normalisation. This preserves the pattern and rates of growth, but allows GDP to be directly compared to the other variables, as illustrated in Annex A. This means that the forecast is not influenced by the units of measurement of the independent variables, but only by their relative growth rates and interactions. The figure shows forecast GDP from 2015 onwards growing at a slower rate than in the period 1956 to 2006, but at a similar rate of growth from 1911 to 1954. The forecast assumes that the historical pattern of GDP growth was associated with a parallel growth in the working age population and growth in higher level educational attainment. The future plateauing in the working age population and educational attainment is, therefore, modelled as having a negative impact on GDP growth in line with Gordon's argument of economic headwinds (Gordon, 2012 and 2015).

Fewer workers, with unchanged productivity and investment, would automatically reduce growth and output.

This GDP forecast generated may be optimistic, especially the suggestion of no serious recessions. However, this is what the data and the analysis suggests using the MSSA method with a ten-year window. The ten-year window reduces the smoothing produced by a 75-year window and makes the business cycles apparent, as it smooths over a shorter time-frame. The method also maximises the value of the long historic data series to obtain the cyclic patterns and relationships between the variables, as well as using the working age population and its attainment to produce a set of predicted time series. The method assumes that the business cycle is driven by endogenous factors, with external disruptive change only impacting on GDP growth when the economy is weakened by a range of underlying cyclic changes. This means that to an extent the forecast should be seen as indicative, rather than absolute, as the scale and nature of all the possible external shocks cannot be known. The forecast for real investment shows a more dynamic picture in Figure 4.4, with a much more cyclical pattern.

The results of this GDP forecast, generated by MSSA, has implications for the LCT. Given the lower rate of GDP growth revealed by the analysis in Figures 4.3 and 4.4, potentially, there is likely to be lower average rates of return on investments which, in turn, would reduce the incentives to maintain steady investment patterns. However, sustained investment is key to the success of the LCT. Figure 4.4 also reveals that productivity per capita shows a steadier pattern of growth, but at a lower rate than over the previous 50 years. This slowing of productivity growth is consistent with many of the narratives surrounding the concept of secular stagnation (Eichengreen, 2015; Gordon, 2015).

Figure 4.4: MSSA forecast of UK Real GDP, Investment and Productivity



Source: MSSA Forecast

The chart 4.4 also shows the time series for the predictor variables and co-evolving variables in this MSSA analysis. This produces parallel forecasts of investment and productivity, which are both used later to calculate the employment impact of the LCT. Finally, the chart also shows a levelling off in the growth of the population and the average level of educational attainment, which is reflected in the lower growth rates of the MSSA forecast variables. Given the method used, this means that reductions (increases) in population and education attainment have been linked to reductions (increases) in GDP growth. This again, could have implications for the success of the LCT in terms of the ability to mobilise the required investments, as this shows reductions in growth of the working age population leading to a reduction in future GDP growth rates. These lower GDP growth rates than otherwise forecast have important implications for the LCT, as they show that even with a business as usual scenario emissions would not increase as much as other models suggest, as emissions are linked to GDP. This, in turn, means that it will be easier than otherwise to meet the carbon reduction targets required.

The upper turning points in the business cycles forecast by the MSSA routine are in 2024, 2033, 2042, 2050 and 2060, based on the turning points for real investment. As mentioned before, these forecasts are not absolute predictions but, in practice, the actual future dynamics and trends are likely to be similar to those presented here if an endogenous basis for the business cycle is accepted (Dosi et al., 2006).

This MSSA based economic forecast developed here provides the basis for a core scenario of construction activity developed in Section 4.4. However, before this the construction forecast the MSSA based forecast is compared with other long-term economic forecasts.

4.3.5 Comparable long-term forecasts

There are surprisingly few comparable long-term forecasts and those that are published tend not to reveal the full details of their methodology. There are a series of long-term forecasts designed to provide support to climate studies and these are examined first.

Socioeconomic pathways

An example of the use of scenarios for the LCT is the GDP scenarios underlying a series of climate change socioeconomic pathways by O'Neill et al., (2015). These have a similar purpose to the proposed scenario in this thesis, in that they are designed to identify more clearly any potential economic problems for the LCT. The focus is on the scale of investment required for addressing climate change and the economic consequences if the mitigation and adaption measures are not sufficient.

Furthermore, the O'Neill et al. scenarios are also based a shared set of population scenarios (KC and Lutz, 2014), similar to the approach adopted by the thesis. These scenarios were based on a wide range of population scenarios and economic growth assumptions producing an equally wide range of economic scenarios (Dellink et al., 2015). In contrast to the methodology adopted here, although O'Neill et al.'s scenarios sought to examine long-term trends, no effort was made to identify and project business and other cycles (Leimbach et al., 2015). The absence of business cycles is not a problem for these socioeconomic pathways, as they concentrate on long-term trends rather than the dynamics of the business cycles. However, this is problematic when forecasting low-carbon skills, given the impact of the business cycle on the construction sector, as identified in Chapter 2.

Consultancy forecasts

There are a range of long-term forecasts produced by consultancy groups, often with little documentation of the methods or assumptions used. Economist Intelligence Unit (EIU) produced GDP forecasts to 2050. The EIU methodology used is described as a "supply-side framework, in which output is determined by the availability of labour and capital equipment and the growth in productivity" (EIU, 2015) This uses comparable data to that used by the MSSA based forecast generated here, but, in contrast, only provides GDP estimates for 2015 and 2050 of 2,951 US$ bn and 9,826 US$ bn respectively.

PriceWaterhouseCoopers (Pwc) have also produced some long-term GDP forecasts shown in Table 4.1. There are even fewer details about the methodology adopted or the drivers taken into account when forecasting GDP. This shows a straight-line growth at a faster rate than forecast using the MSSA method. This illustrates the impact of not modelling in business cycles or the impact of demography.

Table 4.1: Forecast GDP in 2014 PPP US$ billions

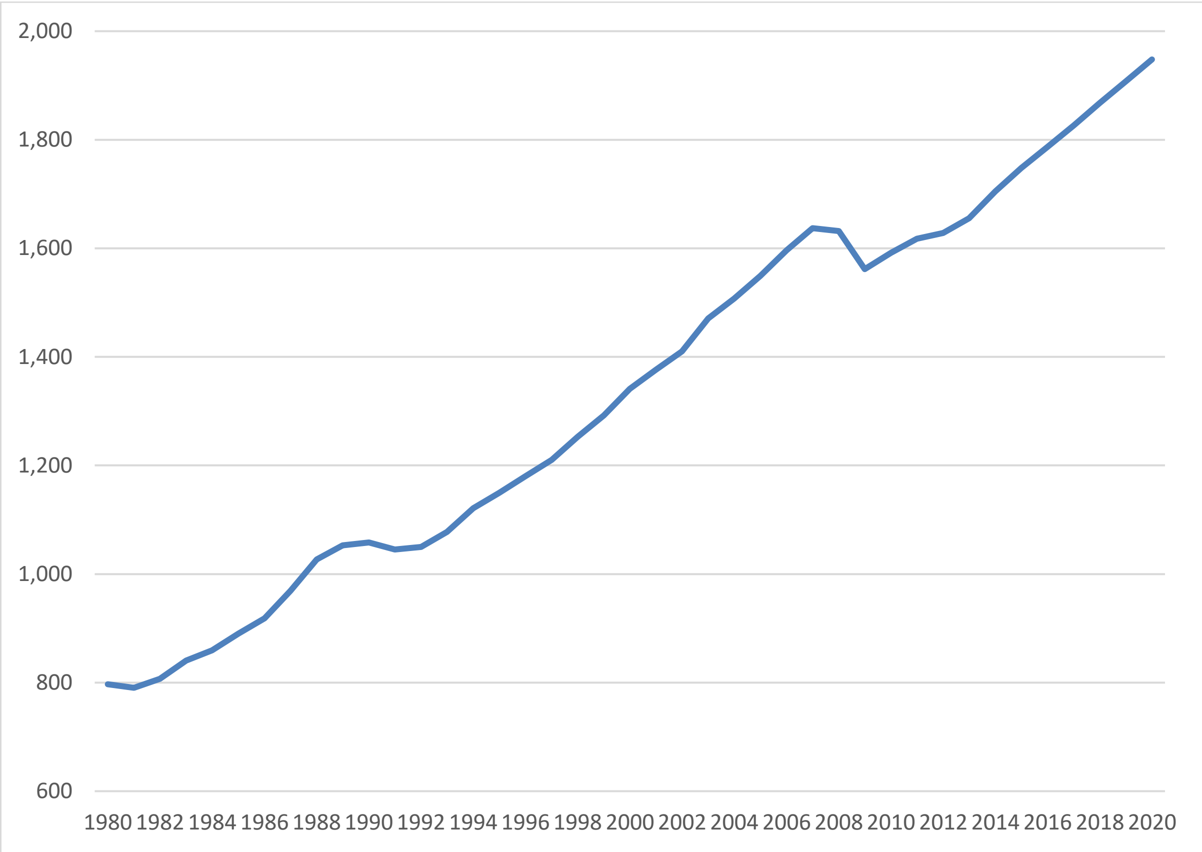
	2014	2030	2050
UK	2,435	3,586	5,744
US	17,416	25,451	41,384
China	17,632	36,112	61,079

Source: Pwc (2015) The World in 2050 p: 3

IMF forecast

The International Monetary Fund's (IMF's) longest available forecast for the UK is up to 2020 based on data up to 2014 and again is over too shorter time scale to inform the LCT. Figure 4.5 plots the actual and forecast GDP in millions of constant UK pounds. The chart shows that the IMF foresees the UK economy returning to long-term growth rates from 2015.

Figure 4.5: IMF UK GDP Forecast

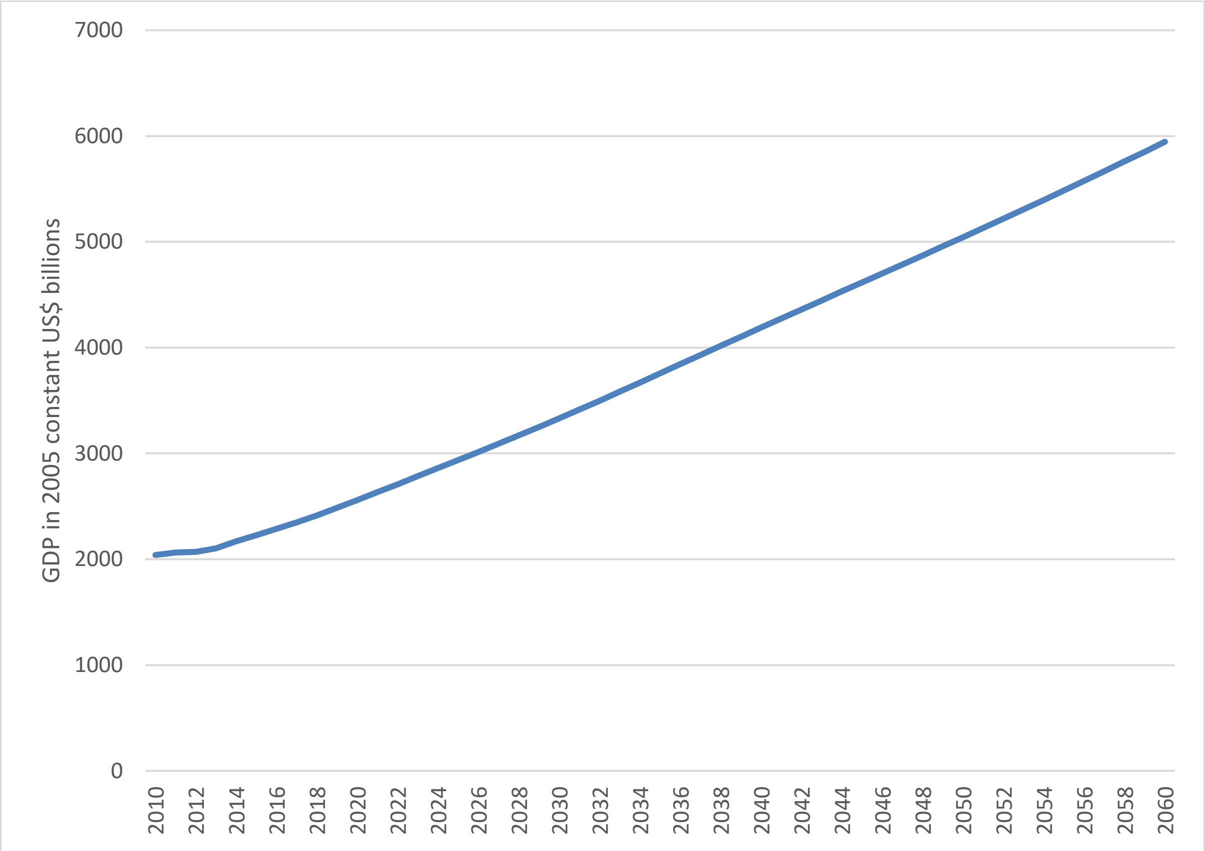


Source: International Monetary Fund

OECD forecast

A more detailed forecast (Figure 4.6) comes from the Organisation for Economic Co-operation and Development (OECD) which provides the details of the methods adopted (OECD, 2014a).

Figure: 4.6: OECD Long-term GDP forecast for the UK



Source: OECD (2014a) OECD Economic Outlook No. 95

Again, this long-term forecast also settles down to a straight-line progression with a higher average growth rate than forecast using the MSSA method. However, another OECD note published in the same year details the possible and varied forces that could reduce the rate of economic growth, which include demographics and the plateauing of educational attainment (OECD, 2014b).

Summary of forecasts

Table 4.2 brings together the various long-term forecasts to allow comparisons to be drawn between them.

Table 4.2: Summary of long-term third party UK GDP forecasts

	2014 in US$ bn	2050 in US$ bn	Average Annual Percentage Growth 2014 - 2050
Sociotechnical pathways	No separate forecast for the UK		
Pwc	2,435	5,744	3.8
Economist Intelligence Unit	2,951	9,826	6.5
IMF Forecast *	1,748	3,148	2.2
OECD Long-term	2,229	5,043	3.5
Core MSSA economic forecast **	2,569	3,326	0.8

*Note * IMF forecast to 2020 linearly extrapolated to 2050, ** in UK £ bn*
Source: Own Analysis

This shows the wide divergence between the forecasts, from usually similar starting points. The table also shows that new core economic forecast generated here using MSSA has a significantly lower average annual growth rate over the period. This is significant, as arguably the MSSA based forecast more adequately takes into account the economic headwinds that the economy will face over the period (Gordon, 2012).

Discussion

The bulk of these economic forecasts essentially show growth returning to the long term trend. The literature around secular stagnation argues that declining population growth and plateauing educational attainment, amongst other factors, will lead to a slowing of the long-term growth rates (Gordon, 2012). Any change in the demographic structure and reduced population growth in the UK will have a major impact on GDP growth (Aksoy et al., 2015). Therefore, taking account of population growth and structure improves economic forecasts (Bloom et al., 2007). Moreover, although demographics cannot explain all the secular stagnation currently impacting European economies, it can explain low long-term growth (Favero and Galasso 2015) and has many potential impacts. For example, it is argued that an ageing population leads to higher wages and, hence, to lower growth (Krueger and Ludwig, 2007). An ageing workforce also can reduce entrepreneurship (Liang et al., 2014) and it is suggested reduce innovation (Zimmermann, 2016). At the same time, the changing age structure is also linked to a shift in resources from investment to consumption (Bloom et al., 2001; Ludwig et al., 2012). Likewise, the plateauing of educational attainment will have similar implications given the importance human capital has had on growth so far (Nelson and Phelps, 1966; Barro and Lee, 2015). All these influences potentially impact on the success of the LCT in terms of investment and supply of skills.

The MSSA technique allows these diverse influences on the pattern of growth from population growth, population structure and educational attainment to be included in a forecast, without the exact relationships being completely understood or parameterised, as it is a model-free technique. This means that it draws upon the historical relationship between these factors and growth to predict future growth. This again makes the technique advantageous, as it also allows a more sophisticated forecast to be produced, rather than simply producing a straight line pattern of growth, even when it is known that important changes are occurring to the population structure. There may well be other headwinds that will impact on the future pattern of economic growth (Gordon, 2012), but the size of the working age population and its educational attainment are relatively reliably forecastable as predictors of the future and, as such, have been adopted as the most appropriate predictors to use for the core MSSA forecast.

4.4 Forecasting construction activity based on GDP

This section examines the relationship of construction activity to GDP and GDP growth. This examination allows translation of the core economic forecast from the MSSA analysis into a construction activity forecast. The historical relationship between the whole economy and construction activity is used to produce a forecast to predict the pattern of construction activity over the period of the transition, based on the preceding economic MSSA analysis.

4.4.1 Construction, GDP and investment

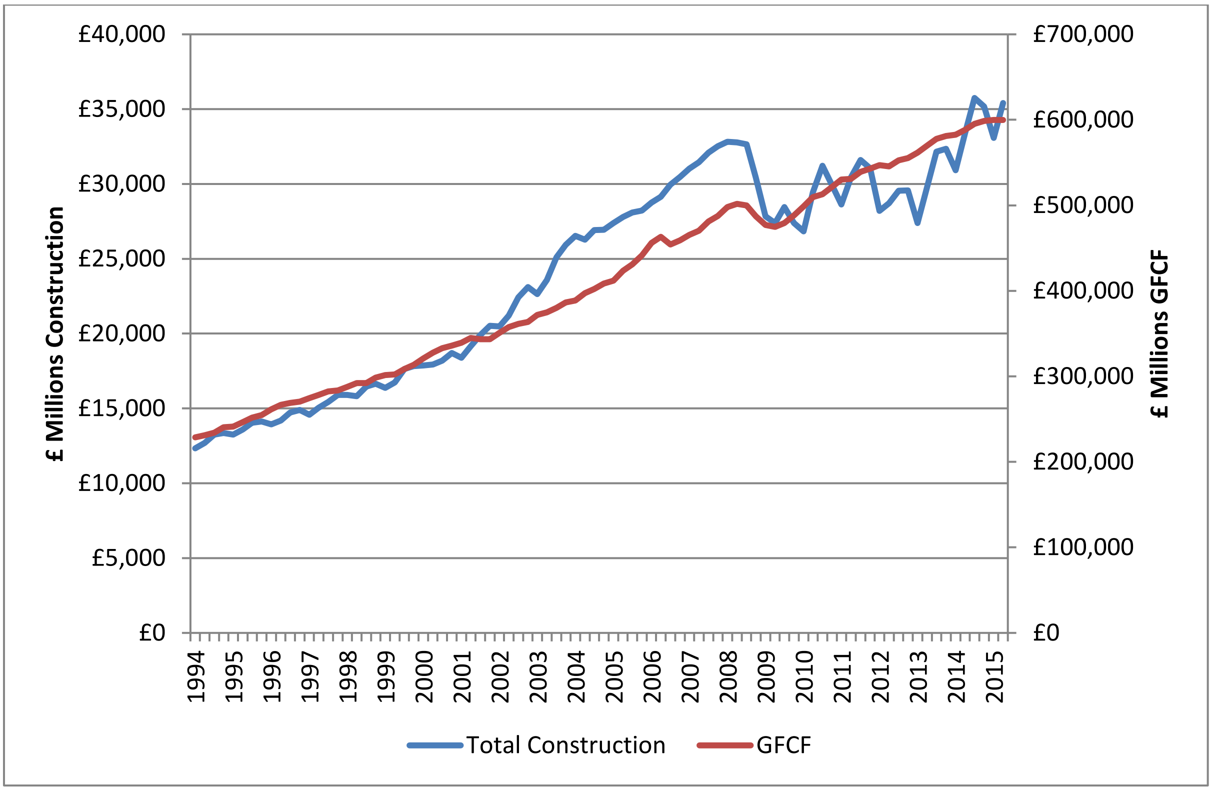
The construction sector is more complex than traditional forecasts which are based solely on GDP and its drivers and do not reflect well the dynamics of the sector in the context of the business cycle. Chapter 2 examined the response of the construction sector to business cycle shocks in subsection 2.4.1. This showed the construction sector responding to the business cycle in a dramatic way (See Figure 2.7, page 41). Indeed, some commentators consider the construction sector to drive the business cycle rather than the other way around (Leamer, 2007).

The analysis of the time series data produced indicates that the sector responds to crises by stopping recruitment while trying to hold on to the more qualified workers, as shown in Chapter 2. Therefore, holding on to staff could lead to reduced productivity in construction activity as utilisation is reduced. Equally, the collapse in apprenticeship training since the 2008 crisis could lead to a longer-term reduction in productivity, as the skills available decline. However, a particular feature of the UK construction sector is the increase in construction sector self-employment during crises (Behling and Harvey, 2015). This is, partly in response to the tax advantages, but also because of the increased flexibility that sub-contractors provide to the larger construction companies.

This relationship between GDP and construction activity means that, while construction activity is an important component of GDP, GDP alone is not a very good predictor of construction activity. An alternative, but still a partial, predictor of construction activity is Gross Fixed Capital Formation (GFCF) or investment.

This is illustrated in Figure 4.7 which shows that investment more accurately reflects the changes that occur in construction activity. To a degree, this is to be expected, as much investment involves construction. However, it is clear that other factors are also involved in determining the level of construction activity. For instance, the graph illustrates that during upturns in economic activity construction activity exceeds that suggested by the investment figures. On the other hand, during downturns the activity drops below that suggested by the GFCF figures. A detailed examination of the data indicates that this is due to private house builders concentrating their activities at the top of the business cycle where they expect to sell properties for the maximum amount of money (Muellbauer and Murphy, 2008).

Figure 4.7: Construction Activity and Gross Fixed Capital Formation (GFCF)



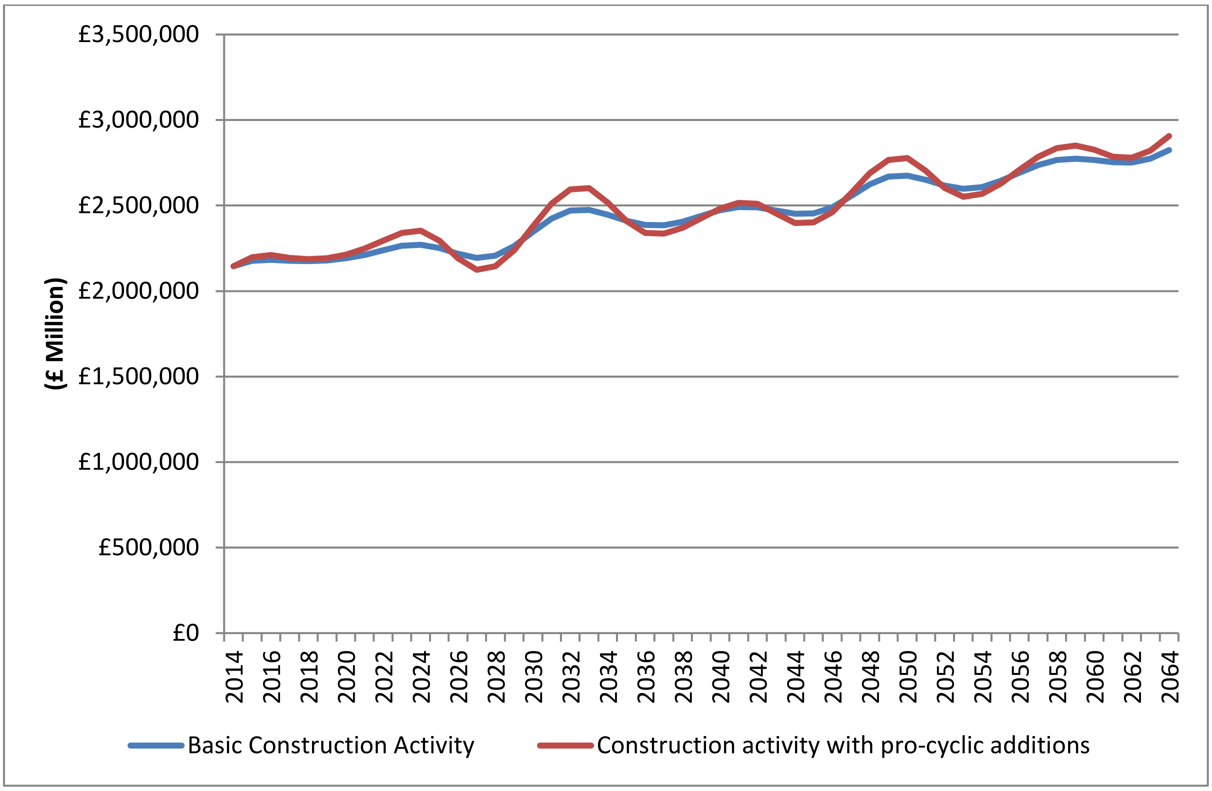
Source: ONS Quarterly Construction Statistics and ONS Quarterly GDP component statistics

Figure 4.7 shows that that the pattern of growth in demand for construction will be complex and only partially linked to GFCF, with sharp downturns in construction activity when GFCF drops during a recession. Importantly, the new long-term MSSA economic forecast suggests that history will repeat with many booms and busts in construction activity before the LCT completes. These booms and busts will lead to cycles of recruitment and loss to the construction workforce (Hadi, 2011). In turn, this could create skill shortages and the requirement for more training than a stable growth pattern would demand. The complexity of the relationships between the economy and construction skills means that a mathematical relationship is not possible, and would not be able to reflect developments accurately. As a result, the next subsection develops a core scenario which represents a plausible and evidence-based assessment of the probable developments.

4.4.2 The core construction forecast

The next stage of the proposed forecasting methodology is to generate a core construction forecast. This builds on the long-term MSSA based forecast documented in Section 4.3, in particular, the investment time-series, as this most clearly shows the cyclic pattern characteristic of the construction sector. The core forecast is based on the observation that the pattern of construction activity shows a more dramatic pro-cyclic pattern than the GFCF cycle. Therefore, the core construction forecast here is based on an exaggerated version of the forecast GFCF trend. This is achieved by taking the growth rate in gross fixed capital investment and increasing it by 1.7 percent during upswings and decreasing it by 2.9 percent during downswings. This method generates the historic pattern and produces a plausible forecast of construction activity.

Figure 4.8: Investment Driven Construction Activity Plus Pro-Cyclic Additions

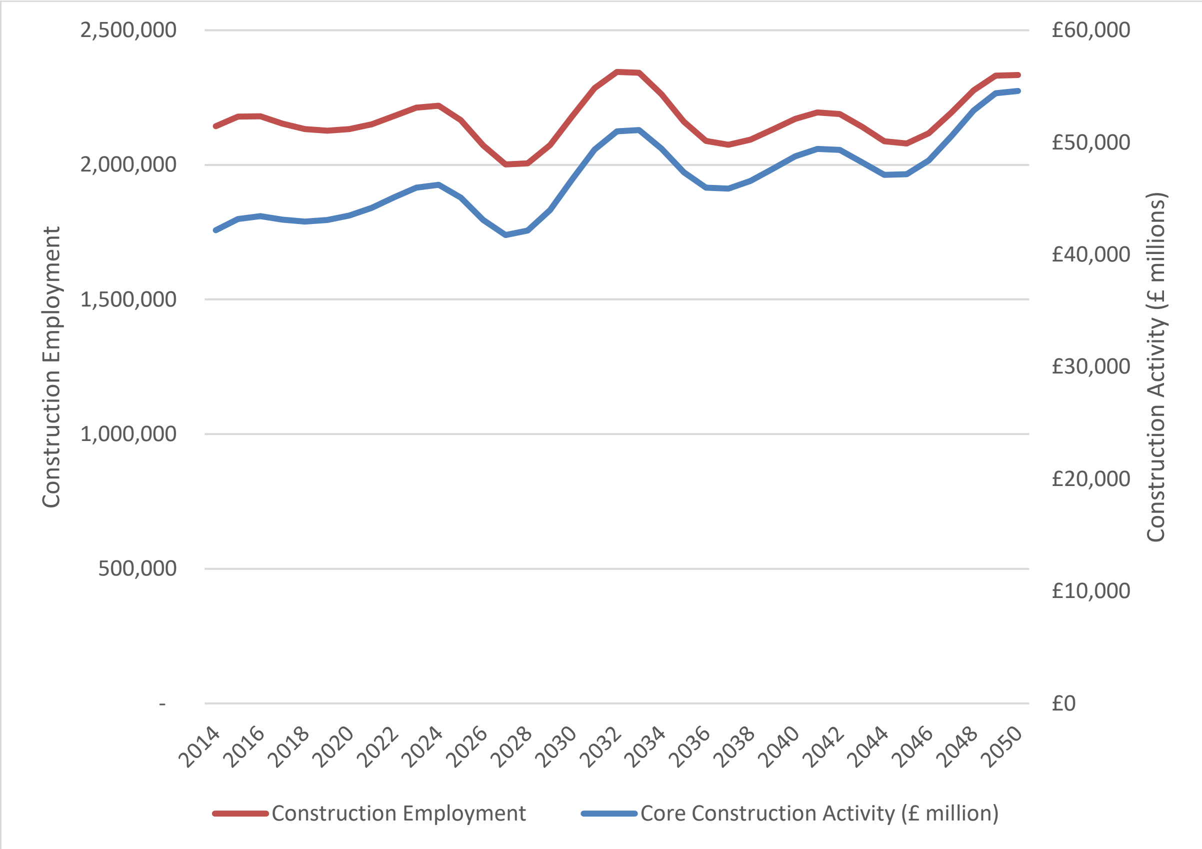


Source: MSSA forecast

4.4.3 Construction employment forecast

The next step in the forecasting methodology is to produce a construction employment forecast. Construction activity is relatively simply translated into construction employment by using the employment to output ratio from subsection 4.4.1. Then the impact of productivity increases from subsection 4.3.4 are incorporated to produce and overall forecast. The economy wide productivity forecast is used rather than any specific construction sector productivity as the impact of productivity on the construction has been historically difficult to measure (Abdal-Wahab et al., 2008). See Chapter 5 for a fuller discussion of construction productivity.

Figure 4.9: Construction Employment Forecast



Source: Own Analysis

The results of the construction employment forecast are shown in Figure 4.9. It shows that the combination of the business cycle, slow overall growth and improving productivity, means that peak construction employment is reached in 2032 and by 2050 employment is nearly back to the 2032 levels. It also shows the potential impact of the business cycle on construction employment, with two dramatic downturns in construction employment with minima in 2027 and 2037. The forecast business cycles are based on internal endogenous pressures and historic cyclic patterns, however there is scope for external factors pushing the economy into recession such as wars or natural disasters Regardless of the timing of cycles, the forecast illustrates the impact of such cycles on construction employment. Chapter 2 has shown the impact of the downturns which lead to a reduction in recruitment and training, which in turn requires greater efforts during the upturns to avoid skill shortages.

4.4.4 Construction occupational forecast

The next methodological phase is the production of a construction occupational forecast. All things being equal, the future occupational structure should be the same as the current occupational structure. However, it is known that the occupational structures are changing and need to be examined. The UKCES Working Futures forecast, over a 10-year period, uses occupational change at the sectoral level over the previous four years as the basis for forecasting over the 10-year horizon (Wilson et al., 2016). Due to common data availability issues, the rolling forward of the recent past is the method used internationally for occupational forecasting (Wilson et al., 2004). Unfortunately, this method rolled forward for 50 years is likely to generate anomalous results and so is not easily applied to forecasting over the longer period of the LCT. This is because the changes to skill profiles, at least partially, reflect changes in the direction of innovation. It is unlikely that the skill biases of innovation will remain constant over the period, especially given the forecast changes in educational attainment amongst the working age population. Therefore, an alternative approach is required which needs to start from what is relatively reliably forecastable about the labour market in 2050 in order to produce a reliable forecast for the LCT.

Therefore, the Barro and Lee (2015) forecast for working age educational attainment to 2040 is utilised. This uses data on educational attainment and can be rolled forward on the basis of annual cohorts entering and leaving the working age population.

Table 4.3: Forecast Educational Attainment of Working Age Population in 2050

	2015	2050	Percentage increase
Tertiary	27.8	35.2	26.6
Secondary	61.7	60.8	-1.5
Primary	10.4	3.9	-62.5
No Schooling	0.1	0.1	0.0
Total	100.0	100.0	

Source: Own Analysis and Barro and Lee (2015)

This means that reliable estimates of the attainment profile of the working population in 2050 can be produced, as shown in Table 4.3. This economy wide forecast of changes in educational attainment can then be combined with a breakdown of educational attainment by occupational level within the construction sector. Table 4.4 provides such a breakdown for 2015.

Table 4.4: Educational Attainment of Construction Workforce by Occupational Level, 2015

	Degree or equivalent	Sub-degree post compulsory	GCSE & other qual-ifications	No qual-ifications	Total
Managers	56,000	110,600	49,200	12,700	228,400
Professionals	98,400	62,100	19,200	6,200	185,800
Associate Prof	35,400	56,900	23,800	**	118,500
Administrative	22,600	47,500	64,000	6,700	140,800
Skilled Trades	41,200	583,900	370,900	112,600	1,108,600
Sales and Service	**	7,400	7,700	**	20,000
Operatives	**	46,300	82,300	23,300	157,300
Elementary	9,500	40,800	82,600	36,700	169,500
Total	271200	955,400	699,500	202,900	2,129,000
Percentage	12.7%	44.9%	32.9%	9.5%	100.0%

*Notes: ** indicates values below reporting level of 6,000 suppressed and figures rounded to nearest 100 which means columns and rows may not completely sum*
Source: Own Analysis of Annual Labour Force Survey

Using the basis of the growth in tertiary and secondary qualifications forecast from Barro and Lee, combined with the current pattern of educational attainment shown in Table 4.4, the next step is to produce a forecast for the occupational profile in 2050. The results are shown in Table 4.5. This shows that occupations with a higher proportion of tertiary qualified staff, such as managers and professionals, are forecast to expand. At the same time occupations such as skilled trades with high proportions of secondary level qualifications are projected to decline. Given that the construction sector has been historically dependent on skilled trades and vocational qualifications, this analysis suggests a slight reduction in this dependence as the sector absorbs more graduates. This, in turn, means it should be easier to staff the sector and therefore make achieving the LCT more likely.

Table 4.5: Construction Occupational Breakdown in 2015 and 2050

	2015		2050 unadjusted		2050 adjusted	
Managers	228,400	10.7%	250,400	10.7%	281,800	12.1%
Professionals	185,800	8.7%	203,700	8.7%	266,000	11.4%
Associate Prof	118,500	5.6%	129,900	5.6%	146,600	6.3%
Administrative	140,800	6.6%	154,300	6.6%	141,700	6.1%
Skilled Trades	1,108,600	52.1%	1,215,300	52.1%	1,174,100	50.3%
Unskilled	346,800	16.3%	380,200	16.3%	323,600	13.9%
Total	2,129,000	100.0%	2,333,800	100.0%	2,333,800	100.0%

Notes: estimates rounded to the nearest 100; columns may not completely sum
Source Own Analysis

Within these broad occupational groups, the detailed occupations are much more subject to technical change and are hence much more difficult to predict. This is because these detailed occupations are often orientated towards specific technologies so are more exposed to change.

This means that Table 4.6 shows the breakdown of the skilled trade group into detailed occupational categories in 2015. The table also shows the size of these categories in 2050 simply adjusted to the total unadjusted size of the skilled trades group. This is a necessarily crude estimate of the numbers in each trade.

Additionally, the final column of Table 4.6 provides an indication of those detailed occupations that are likely to expand or contract as measures to reduce CO2 emissions are introduced. Standard Occupational Classification (SOC) category 5225 ‘air-conditioning and refrigeration engineers’ are likely to expand significantly with the more widespread adoption of air and ground source heat-pumps. Demand for SOC category 5241 ‘electricians and electrical fitters’ are also likely to expand as more photo-voltaic panels and home automation systems are installed. Similarly, home automation is likely to lead to an increase in demand for SOC 5242 ‘telecommunications engineers’. Further adaption to achieve the targets for reducing emissions include changing heating systems from gas fired systems to heat-pump driven systems which is likely to lead to an increase in demand for SOC 5314 ‘plumbers and heating and ventilating engineers’. In addition, the increased use of wood frame buildings, due to their environmental performance and reduced embedded carbon, will probably lead to an increase in demand for SOC 3515 'carpenters and joiners'. Conversely, a concern about embedded carbon associated with cement will likely see a reduced demand for SOC 5312 'bricklayers and masons'.

Table 4.6: Construction Skilled Trades in 2015 and 2050

	2015		2050 adjusted	
	(n)	(%)	(n)	
5215 Welding trades	8,100	0.7%	8,900	
5216 Pipe fitters	6,400	0.6%	7,000	
5223 Metal working production and maintenance fitters	20,700	1.9%	22,700	
5225 Air-conditioning and refrigeration engineers	12,200	1.1%	13,400	++
5241 Electricians and electrical fitters	132,900	12.0%	145,700	+
5242 Telecommunications engineers	15,300	1.4%	16,800	+
5249 Electrical and electronic trades n.e.c.	13,900	1.3%	15,200	
5311 Steel erectors	6,800	0.6%	7,500	
5312 Bricklayers and masons	65,900	5.9%	72,200	-
5313 Roofers, roof tilers and slaters	38,700	3.5%	42,400	
5314 Plumbers and heating and ventilating engineers	135,800	12.2%	148,900	+
5315 Carpenters and joiners	201,000	18.1%	220,300	+
5316 Glaziers, window fabricators and fitters	21,300	1.9%	23,300	
5319 Construction and building trades n.e.c.	197,900	17.9%	216,900	
5321 Plasterers	45,500	4.1%	49,900	
5322 Floorers and wall tilers	36,000	3.2%	39,500	
5323 Painters and decorators	83,900	7.6%	92,000	
5330 Construction and building trades supervisors	39,900	3.6%	43,700	
Other skilled trades	26,400	2.4%	28,900	
	1,108,600	100.0%	1,215,300	

Note: estimates rounded to the nearest 100
Source: Own Analysis of 2015 Annual Labour Force Survey

Despite the plausible trends at the level of SOC categories, the detailed pattern within the construction sector is unclear, as change will be driven by technical change which, in part, will be driven by the availability of skills and /or disruptive skills shortages. This implies a dynamic co-evolving system will determine the future detailed occupational structure of the construction sector. Equally, to a large extent, the direction of occupational demand will be driven by the technical changes and options adopted by the UK government to address the demands of the LCT. These technical-change driven occupational changes are addressed in detail in the next chapter, Chapter 5. However, the impact on the LCT of the more general occupational trends forecast in the construction sector are now discussed.

4.4.5 Implications for the low-carbon transition

The construction sector is more dependent on skilled trade occupations than most other sectors. Within construction these skilled trade occupations are currently mainly filled by people with secondary or primary qualifications. The results of the occupational forecast produced have indicated that the secondary and primary level qualifications, as a proportion of the workforce, are projected to decline significantly by 2050. It is possible that graduates from other discipline could enter these occupations traditionally reserved for the vocationally qualified, however this is unlikely. This means that providing additional skilled trades will be problematic and could see a sub-optimal number of skilled trades available. This is before there is any additional technical change demand on the construction workforce induced by the LCT. The next chapter, Chapter 5, addresses this additional demand. Additionally, there is also a range of proposed UK policy options, unrelated to the LCT, that could produce even greater demand for construction employment. These options are examined in Chapter 6.

However, it is clear that without significant changes to construction productivity or technologies the continued growth in baseline construction activity will potentially pose a problem for the LCT, as the number of young labour market entrants, the traditional source of construction workers, as shown by the results, is projected to increase at a slower rate than the demand from the sector. This implies potential recruitment problems for the sector, so efforts to retain staff will be increasingly important to address the needs of the LCT. This will be in addition to the demands for increased general construction output.

Having produced forecasts to examine the thesis question "how the economy and associated levels of construction activity will impact on demand for construction skills" the additional impact of technological change on construction is examined. The technical and institutional responses to this problem are addressed in Chapters 5 and 6. Equally, these chapters also examine whether the technical options and policy environment might further exacerbate the problem. Chapter 7 draws together the analyses in Chapters 4, 5 and 6 and examines the implications for the LCT and, where appropriate, makes recommendations to reduce the potential for disruptive skills shortages which might impact on the success of the LCT.

5 – Technical Change and Low-Carbon Construction

5.1 Introduction

5.1.1 Aims and outline

Chapter 3 has identified technical change as one of the factors that impact on the demand for skills needed to achieve the Low Carbon Transition (LCT). However, to date, there have been no forecasts that address the LCT's demand for the skills necessary to build and install low carbon technologies. There are existing forecasts that provide the costs and scale of the impacts of the various technologies needed to achieve the LCT, but these are not related to the employment or skills consequences. As an additional complexity, no one technology is sufficient to meet the competing requirements of reducing CO2 emissions to a level that reduces global warming, provide energy at low cost, and provide stable supplies of energy, as demanded. To meet these multiple requirements a complex bundle of energy-producing technologies, often termed a pathway, needs to be constructed. This chapter aims, for the first time, to provide a method for forecasting the impact of low-carbon technical pathways on UK construction employment and the demand for specific skills over the long-term of the LCT.

The various pathways to the LCT have two main skill consequences. The first is the increased demand for construction labour and the second is the potential for skills shortages in particular occupations, shortages that could critically disrupt the transition. The chapter outlines the characteristics and costs of the various pathways to the LCT, and shows how these costs can be used to calculate the required construction workforce and how critical occupations can be identified. The chapter then implements these methods and discusses the implications for the LCT of the various technical choices.

The Department for Energy and Climate Change (DECC) pathways have been selected as they use a common framework to assess a wide range of technical options. The forecasting process adopted uses a link between construction costs and employment for different sub-sectors of construction in order to calculate numbers of construction workers associated with the pathway. Finally, using the forecast of future productivity from Chapter 4, the impact of productivity growth on the forecast numbers is calculated.

The four pathways used to illustrate the impact of technical choices are:

- High-nuclear pathway – produced by DECC
- High-renewables and deep-retrofit pathway produced by the Friends of the Earth (FoE)
- National Grid's business-led pathway, and
- DECC's version of the academically produced MARKAL 3.26 least cost pathway.

These have been selected as they represent a divergent range of technical pathways and the different underlying approaches to the transition that, between them, illustrate the contested nature of the LCT.

5.1.2 Context and basis for methodology

Using the Tripartite Model of skills demand developed in Chapter 3, this chapter seeks to address this lacuna which, if not dealt with, could have serious consequences for the success of the transition. Without forecasts to identify the large numbers of workers and specialist skills required for implementing technical change, serious skill shortages could occur.

The Tripartite Model argues that skills demand is dependent on three factors; underlying demand, technical-change-driven demand and institutional-change-driven demand. Using this model, Chapter 4 examined the underlying construction skills demand and proposed a new approach to economic forecasting to reflect the long timescales of the Low-Carbon Transition (LCT). This chapter now addresses the second of the three legs of the Tripartite Model, which is the impact of technical change on the demand for skills as part of the LCT. It aims to produce a series of forecasts that will identify the additional numbers of people that will be needed to construct or install the necessary low carbon technologies for each of the technical options available.

As mentioned in Chapter 1, DECC has produced a series of pathways to 2050 detailing the technical options that can ensure that the UK meets its climate change and carbon reduction targets. These pathways involve the selection, scaling and timing of a series of energy production and conservation technologies, using DECC's 2050 pathway tool (DECC, 2010a). The tool is a spreadsheet-based model that integrates the costs and consequences of a wide range of possible technological options, which could be used to achieve the 2050 low-carbon targets.

The four DECC pathways that have been selected for the basis of the forecasts here have been chosen to provide a series of LCT possibilities, from a centralized high-nuclear route, via a business-led route and a least-cost route, through to a high-renewables route. Importantly, the pathways represent a coherent bundle of technologies that met a range of the UK Government's criteria including achieving the required carbon reductions and providing a balanced mix of energy sources that provide energy security. Most of the available technologies are in all of the pathways but with differing emphases depending on the objectives of the pathways' developers. They represent the dominant technological options available to the Government to achieve the transition. These four pathways also reflect three different patterns of governance and investment that could provide a way to achieve the LCT (Foxon, 2013).

This chapter uses the 'point' fixed capital costs linked with the selected technical elements of each of the four DECC 2050 pathways as the basis for generating four costed forecasts for the construction industry. These forecasts are then used to calculate the additional employment associated with each of the four low-carbon technology pathways. The employment forecasts use a breakdown of activity by construction subsectors, as each subsector has a distinctive skill profile. As these initial forecasts do not account for growth in construction productivity or technical learning, further analyses and forecasts are then undertaken to address these important factors. Despite the known impact of technical change on construction, and the scale of the required low-carbon investments, this is the first time that such comparable employment forecasts for these long-term pathways have been generated.

However, although these technical change employment forecasts help to understand the DECC pathways, they need to be put in context of the overall construction employment. This allows the potential size of any shortages created by the LCT to be better understood. Therefore, in order to measure the overall impact of underlying growth and technical change on construction employment, the next step in the proposed forecasting method is to combine these forecasts with the underlying construction activity forecast produced in Chapter 4. This brings together the technical-change second leg with the underlying-demand first leg of the Tripartite Model.

Integrating the low-carbon data and the underlying growth will provide a better basis for determining whether or not the UK construction sector will be able to address the additional LCT demand. The intention is that this combination of underlying demand and technical change will better inform policy development than the current short-term forecasts, which do not explicitly incorporate technical change. Chapter 5 also prepares the ground for the integration of the further impact of institutional change, the third leg of the proposed Tripartite Model, to be covered in Chapter 6.

5.1.3 Structure of the chapter

This chapter consists of four further sections:

- An introduction to the DECC 2050 pathways that provides background details of the selected pathways including their costs and an initial analysis of the potential impact on construction skills demand of the pathways
- Forecasts of technical change employment that link the DECC pathways to construction employment using Annual Business Survey and Labour Force Survey data

- An introduction to the concept of bottleneck occupations and how these could impact on the employment forecasts generated for each of the four pathways, and
- A final section examining the implications of the above for the Low-Carbon Transition.

5.2 Technical options from the DECC 2050 pathways

The following sub-sections characterise each of the pathways in turn below. For each pathway there is a brief description of its key features followed by a brief qualitative analysis of the key occupations and skills that would be involved in the UK construction sector implementing the pathway. The actual forecast employment consequences are explored later in Section 5.4 and the potential skills bottlenecks in Section 5.5.

5.2.1 High nuclear pathway

The DECC high-nuclear pathway emphasises grid-scale electric generation and, as such, represents an example of what Foxon (2013) describes as a ‘centrally coordinated’ transition pathway. Centrally coordinated pathways are described as where, “central government takes a leading role in ensuring the delivery of large-scale, secure, low-carbon electricity supply” (Foxon, 2013: 18).

Recent UK Government policies would appear to be supporting this pathway (Rudd, 2014), perhaps because using DECC’s capital costings this pathway appears to be the cheapest. This policy favouritism makes it necessary to carry out a detailed analysis of the associated skills issues.

Features of the Pathway

As would be expected, the main feature of this pathway is the high reliance on nuclear power. The obvious element of the high-nuclear pathway is the construction of about 30 new 3 Giga Watt (GW) nuclear reactors. The exact number of the nuclear reactors to be built depends on the type and size of the reactors built. The pathway also features the abandonment of many renewable options and efficiency options, as well as a move to more widespread use of electricity for heating, cooking and transport, replacing gas, petrol and diesel. Additionally, the pathway has a high reliance on biomass and carbon capture and storage (CCS) for load-balancing. This is because the output from nuclear reactors provides a constant baseload and is incapable of matching demand by load-following. The high use of biomass for load-following in the pathway drives the 17% of land used for energy crops and high levels of biomass imports. However, the emphasis on biomass has been questioned as it might not be as sustainable and carbon neutral as believed (Haberl et al 2012).

Key occupations and skills

These technical options have skills consequences and what follows is a review of skills that would be linked to the pathway if adopted. A study by the Construction Industry Training Board (CITB) and the Nuclear Skills Academy (Construction Skills, 2011) examines the skill mix involved in nuclear new-build. This suggests that nuclear new-build is dependent on concreters and reinforcement fixers, as well as pipefitters and high-reliability welders. This could be problematic for the success of the LCT, as all of these are occupations reported to have been in shortage by the Migration Advisory Committee (MAC). These reported shortages may reflect the occupational profiles of the large contractors who are more likely to engage with the MAC. Since the large contractors are more likely to be involved in reactor construction the concerns of reactor builders may loom larger for the MAC.

In addition to this, these occupations all have relatively long training and experience requirements and these, combined with the cyclic pattern of demand driven by the business cycle, could predispose these occupations to shortages. This, in turn, means that a high-nuclear pathway is potentially liable to disruption due to skill shortages in these bottleneck occupations. Equally, since nuclear new-build projects require large numbers of these skills, in one place at one time, this could put stress on the skills system, especially if the demand has not been adequately anticipated and a training response put in place.

Annex B1 contains the fuller details of the high-nuclear pathway.

5.2.2 High-renewables and deep-retrofit pathway

Friends of the Earth have developed a high-renewables and deep-retrofit pathway using the DECC 2050 Pathway tool The pathway was designed to show that nuclear power was not essential for a low-carbon future and that the carbon reduction targets could be achieved through renewables, efficiency and behaviour change.

Features of the pathway

The Friends of the Earth pathway focuses on high levels of renewables and deep energy efficiency retrofits of existing buildings. This pathway also includes no nuclear power and relies upon quite extensive behavioural change by consumers. A wide range of renewables is used, with a particular concentration on microgeneration. There is some use of biomass, but on a smaller scale than with the high-nuclear pathway. Generally, the elements involved in this pathway are small scale and local, often with decentralised investment decisions. This makes the pathway an example of what Foxon describes as a ‘Thousand Flowers’ pathway. Such an approach is described as follows: “A more local bottom-up diversity of solutions begins to flourish, with local community leadership in providing decentralised generation and energy conservation options” (Foxon, 2013:19).

Key occupations and skills

An emphasis on small-scale and local electrical generation, coupled with widespread energy efficiency measures and behaviour change, will require the sort of skills common in the small-scale repair and maintenance construction sector. The skills to install solar PV and solar thermal are found amongst domestic electricians and plumbers, alongside some roofing skills. If the

FOE pathway were adopted, the electricians, plumbers, roofers and plasterers required by these low-carbon measures could move in and out of the repair and maintenance sector. Indeed, many of the measures would be installed as part of the normal repair and maintenance cycle. This pathway would put less pressure on the system to provide specific low-carbon skills and make their acquisition easier and less challenging. Equally, it would reduce the risks that the low-carbon skills become redundant in the face of policy or market changes as those involved with low-carbon installations could swap in and out of other roles. This implies that apart from some specific low carbon skills, especially around the relatively new heat-pump technology area, it is less likely that serious skill shortages would impact on this pathway.

However, the reliance on small firms installing microgeneration and energy efficiency measures could bring problems. The Government is currently relying on a process of licensing, whereby workers installing micro-renewables that seek to benefit from subsidies and feed-in-tariffs (FITs) need specific qualifications in order to practice (Jagger et al., 2014). These specific qualifications are relatively expensive to acquire and need to be maintained with periodic re-training and re-examination.

This is a useful mechanism to improve safety and maintain quality that has already been successfully applied to the installation of gas appliances and electrical wiring within the construction sector. However, licensing can also act as a barrier to acquiring and maintaining the necessary skills. If the cost of training and registering for a specific certificate is higher than the marginal increase in income offered to skilled workers who already hold qualifications, then there is no incentive to train. This is particularly the case if the pattern of demand for these new skills is erratic and the payback on the upfront costs becomes uncertain. Given the repeated changes in feed-in-tariff rates and other subsidies as a consequence of changing government and funding policies, the boom and bust pattern of micro-renewable installations could act as a deterrent. Since this high-renewables pathway is dependent on the small scale contractors, and local part of the construction sector, this could be problematic. The balance between raising standards and persuading people to acquire the necessary skills is explored in more detail in Chapter 6, where the impact of institutions and policy on low-carbon skills demand is addressed.

Annex B2 contains the fuller details of the FOE renewables and deep retrofit pathway.

5.2.3 National Grid pathway

The National Grid DECC pathway was developed by the UK company responsible for operating and building both the electricity and gas distribution grids. This role provides them with many insights into the sort of investments that private energy companies are planning to make and are likely to make in the future. This makes this pathway a good example of what Foxon calls a ‘market rules’ pathway. Such a pathway is described as envisioning: “the continued dominance of the market-led logic for the governance of UK energy systems” (Foxon, 2013: 16).

Features of the pathway

The pathway involves limited nuclear power, with about 11 3GW stations built. Generally, most low carbon options, including wind, solar, tidal and efficiency, are involved but to a limited degree. There are relatively high levels of domestic insulation, with over 18 million homes insulated and thermal leakiness down by 42 percent from current levels. Nearly all (80% to 100%) of non-domestic heating will be electric-powered, replacing gas. Perhaps, understandably, there is an emphasis on grid-scale electrical generation capacity, with demand balancing occurring at the grid level. There is also an emphasis on relatively innovative and untried technologies, such as carbon capture and storage (CCS) and tidal power.

Key occupations and skills

Since this pathway is reliant on a wide range of technical options, each only being taken up to a limited extent, there could be a danger that many critical occupations will end up in shortage.

This is because the limited commitment to specific technologies is likely to reduce the incentive to train in areas that appear not to offer long-term careers. This could mean that, despite the more limited commitment to nuclear power, the same skills shortages as those outlined for the high-nuclear pathway are likely to emerge. Conversely, the moderation of the strategy means that the scale of these skills shortages is unlikely to be as great as that of those shortages resulting from large demands for specific skills, but could still be disruptive.

Any shortages that do emerge are likely to be a result of skills that are generic across the proposed technologies and, at the same time, will have long training and experience requirements. For instance, carbon capture and storage (CCS) and combined heat and power (CHP) require pipefitters and high integrity welders. The rarity of these technologies, at least in the UK, could mean that the demand for these skills from such technologies has not been factored into the expectations of employers and individuals. Therefore, this underestimation in demand for these skills by employers could, in turn, lead to shortages due to insufficient numbers undertaking training. The drivers of this sort of skills bottlenecks are further discussed in Section 5.5.

Annex B3 contains the full details of the National Grid pathway.

5.2.4 MARKAL 3.26 least cost pathway

The MARKAL 3.26 DECC 2050 pathway is based on the UK Energy Research Centre's (UKERC's) MARKAL least cost 2050 scenario (Anandarajah et al., 2008). The MARKAL model derives its name from compounding MARK-et AL-location, as the optimisation process is meant to work in the same way that an efficient market would allocate resources. In line with this approach, this DECC pathway uses an optimisation approach to achieve the cheapest combination of technologies that would be necessary to achieve the goal of reaching carbon reduction targets.

Features of the Pathway

The main feature of the MARKAL 3.26 least cost pathway is the diversity of the measures adopted, with very few options taken to an extreme. Given that the business led model of the National Grid pathway is also driven by cost optimisation, it is unsurprising that the MARKAL pathway is very similar to the National Grid pathway. However, the MARKAL pathway puts greater emphasis on low cost options, such as energy efficiency and behavioural change. In comparison, the National Grid pathway recognises that domestic adoption and behavioural change is more difficult to achieve than the plans for cost savings would suggest.

Interestingly, DECC's version of the MARKAL pathway works out more expensive than their high nuclear pathway. However, the DECC MARKAL pathway works out at about the same cost as the National Grid's pathway. DECC has stated that they have used academically validated costs mainly from the UKERC'S MARKAL exercise. However, the lower costs for the high nuclear pathway than the MARKAL pathway implies that, DECC's costs for nuclear power are less than those used by UKERC. Equally, it needs to be realised that these costs are the fixed capital costs, and are therefore, taken to be construction costs but do not include operating or decommissioning costs.

Key occupations and skills

Given the diversity of technologies proposed by DECC'S MARKAL pathway to achieve the transition, there are unlikely to be any specific skills shortages caused by an over-emphasis on any particular technology. However, the concerns from the National Grid pathway about innovative technologies not being factored into skill demand expectations by employers also apply to this pathway. For example, it is likely that the problem with a business led, or cost minimisation led strategy, is that there will be less central coordination to ensure that the required skill mix is in place. Of course, this depends on the pattern of governance and regulation. However, the less central control there is, the less likely it is that adequate training responses will be put into place, especially if limited funding for training is available. Indeed, recent reports state that the lack of central control has been compounded by significant funding cuts, which have reduced central influence over the training system (Keep, 2014).

5.2.5 Cross pathway skills issues

Common to all of the DECC pathways is that the levels of investment in domestic insulation as well as heating and lighting vastly exceed the levels of investment in generation capacity. This indicates the importance of policy measures to encourage domestic investment (Gooding and Gul, 2017). Most of the pathways include a heavy emphasis on heat-pumps replacing domestic gas heating systems. Given that heat-pumps usually involve lower temperatures than gas fired central hating this change of heat source also involves changes to the radiators and pipework (Gleeson, 2015). This provides a further barrier to the widespread adoption of heat-pumps for retrofit situations in addition to the problems of the specialist skills involved in installing and specifying appropriate systems. Any technical innovation that allowed heat-pumps to simply replace existing gas boilers and use existing pipe and radiator installations would address both of these barriers.

A further cross pathway skills issue relates to the importance of civil engineering, including groundworks, for the pathways. This is a special problem for the high-nuclear pathway and less of a problem for the high renewables pathway, but it impacts on all of the pathways to some extent. The problem is that these skills are also those most likely to be in demand as a result of adaptation to climate change and associated sea level rises and increased intense rainfall.

5.2.6 Costs by pathway

The starting point for the analysis of the impact of the LCT on construction employment is the costs provided by each of the four proposed DECC pathways. DECC provide a range of costs from central point costs to a low extreme and a high extreme. The analysis that follows is based on the central point costs. However, the costs remain estimates and the degree of uncertainty that surround them needs to be taken into account. This uncertainty means that the derived employment measures are equally subject to uncertainty. Despite these cautions, these costs represent a consistent set of costings for a wide range of low carbon technologies. Additionally, some efforts have been made by DECC to include the cost savings resulting from greater scale of use of the various technologies.

Table 5.1 provides details of the costs for the elements of the pathways that will be either built or installed by the construction sector. The pathways also include other elements, in particular low carbon vehicles, which have not been included in the analysis.

Table 5.1: Capital Costs by Pathway and Technology 2015 to 2050 (£ millions)

	High Nuclear	Friends of the Earth	National Grid	MARKAL
Conventional thermal plant	£37,625	£8,119	£35,866	£22,679
Combustion + CCS	£1,868	£54,373	£35,813	£30,959
Nuclear power	£197,397	--	£73,148	£83,598
Onshore wind	£27,401	£61,604	£35,719	£23,242
Offshore wind	£51,473	£242,433	£127,641	£70,515
Hydroelectric	--	£1,453	£395	£211
Wave and Tidal	£2,138	£275,244	£7,820	£84,711
Geothermal	--	--	--	--
Distributed solar PV	--	£287,005	£26,297	--
Distributed solar thermal	--	£90,279	£81,251	£90,279
Micro wind	--	--	--	--
Biomatter to fuel conversion	£37,729	£21,868	£33,623	£43,112
Bioenergy imports	--	--	--	--
Agriculture and land use	--	--	--	--
Agriculture and land use	--	--	--	--
Energy from waste	£16,371	£12,022	£16,371	£16,371
Waste arising	£119,738	£104,408	£119,738	£119,738
Marine algae	--	--	--	--
Electricity imports	--	--	--	--
Electricity Exports	--	--	--	--
Electricity grid distribution	£56,448	£159,063	£73,862	£56,239
Storage, demand shifting, backup	£10,325	£21,344	£18,298	£11,782
H2 Production	£3,104	--	--	--
Domestic heating	£744,287	£472,058	£677,341	£610,613
Domestic insulation	£774,297	£11,881	£774,297	£774,297
Commercial heating and cooling	£278,583	£514,433	£180,182	£103,140
Domestic lighting, appliances, and cooking	£125,769	£125,988	£125,988	£125,769
Commercial lighting, appliances, and catering	£1,503	--	£8,585	£14,552
Total	£2,486,058	£2,463,574	£2,452,237	£2,281,806

Source: Interpolated values based on DECC 2050 Scenario costs

Table 5.1 shows the scale of capital investment that will be associated with the LCT. The lowest cost pathway is the MARKAL pathway, which was specifically developed to be low cost.

However, even the MARKAL pathway comes in at just under £2.28 trillion over the period 2015 to 2050. The National Grid pathway is the next expensive pathway at £2.45 trillion, the Friends of the Earth pathway has a similar cost, at just over £2.46 trillion. The High Nuclear pathway, at £2.48 trillion, is the most expensive of the four selected pathways, in terms of construction costs.

Table 5.2: Capital Costs of Technologies by Pathways in 2014 (£ millions)

	High Nuclear	Friends of the Earth	National Grid	MARKAL
Conventional thermal plant	£649	£842	£483	£482
Combustion + CCS	£271	£288	£282	£281
Nuclear power	--	--	--	--
Onshore wind	£1,120	£1,671	£1,246	£1,057
Offshore wind	£1,337	£2,227	£1,844	£1,464
Hydroelectric	£13	£53	£29	£22
Wave and Tidal	--	£103	--	-£35
Geothermal	--	--	--	--
Distributed solar PV	£2	£151	£7	£2
Distributed solar thermal	--	£436	£392	£436
Micro wind	--	--	--	--
Biomatter to fuel conversion	£591	£1,159	£1,686	£1,806
Bioenergy imports	--	--	--	--
Agriculture and land use	--	--	--	--
Agriculture and land use	--	--	--	--
Energy from waste	£240	£247	£240	£240
Waste arising	£2,657	£2,620	£2,657	£2,657
Marine algae	--	--	--	--
Electricity imports	--	--	--	--
Electricity Exports	--	--	--	--
Electricity grid distribution	£840	£1,194	£870	£769
Storage, demand shifting, backup	£103	£143	£118	£108
H2 Production	£10	--	--	--
Domestic heating	£6,717	£7,832	£6,863	£5,785
Domestic insulation	£21,387	£658	£21,387	£21,387
Commercial heating and cooling	£4,835	£9,658	£3,547	£2,677
Domestic lighting, appliances, and cooking	£2,917	£2,934	£2,934	£2,917
Commercial lighting, appliances, and catering	£40	--	£252	£462
Total	£43,081	£32,217	£44,840	£42,515

Source: Interpolated values based on DECC 2050 Scenario costs

Many elements of the pathways were already underway in 2014 and are, therefore, included in the underlying construction forecast of Chapter 4. It is therefore necessary to estimate the costs of the pathways in 2014 to allow these values to be subtracted from the pathways to produce only the additional costs. Unfortunately, the DECC data is only available at five year intervals, so the intervening years data was interpolated using the Stata 'csipolate' function. The interpolated values for 2014 are shown in Table 5.2 and Table5.1 includes interpolated values to provide the total costs.

Table 5.3: Additional Capital Costs to 2050 by Technology and Pathway (£ millions)

	High Nuclear	Friends of the Earth	National Grid	MARKAL
Conventional thermal plant	£14,268	-£22,184	£18,491	£5,321
Combustion + CCS	-£7,904	£43,994	£25,653	£20,854
Nuclear power	£197,397	--	£73,148	£83,598
Onshore wind	-£12,923	£1,464	-£9,154	-£14,808
Offshore wind	£3,348	£162,274	£61,245	£17,822
Hydroelectric	-£469	-£461	-£654	-£581
Wave and Tidal	£2,138	£271,522	£7,820	£85,987
Geothermal	[[	--	--	£0
Distributed solar PV	-£64	£281,562	£26,049	-£66
Distributed solar thermal	--	£74,601	£67,140	£74,601
Micro wind	--	--	--	£0
Biomatter to fuel conversion	£16,469	-£19,868	-£27,084	-£21,904
Bioenergy imports	--	--	--	£0
Agriculture and land use	--	--	--	£0
Agriculture and land use	--	--	--	£0
Energy from waste	£7,731	£3,136	£7,731	£7,731
Waste arising	£24,081	£10,075	£24,081	£24,081
Marine algae	--	--	--	£0
Electricity imports	--	--	--	£0
Electricity Exports	--	--	--	£0
Electricity grid distribution	£26,194	£116,066	£42,526	£28,549
Storage, demand shifting, backup	£6,600	£16,183	£14,037	£7,909
H2 Production	£2,728	--	--	£0
Domestic heating	£502,477	£190,111	£430,270	£402,367
Domestic insulation	£4,357	-£11,791	£4,357	£4,357
Commercial heating and cooling	£104,532	£166,733	£52,491	£6,783
Domestic lighting, appliances, & cooking	£20,761	£20,348	£20,348	£20,761
Commercial lighting, appliances, and catering	£72	--	-£488	-£2,080
Total	£911,793	£1,303,765	£838,007	£751,281

Source: Own Analysis of Interpolated DECC Pathways Data

Table 5.3 provides the results of subtracting the 2014 expenditures from each year's overall costs and then aggregating over the years. This shows the same ranking of the costs by pathway as the overall costs. Importantly, as many pathways involve sharp and sustained reductions in expenditure for specific technologies compared with 2014 it is often the case that negative figures emerge in Table 5.3. Negative costs associated with specific technologies imply that the labour that would have been linked to the technology is released to work on other technologies. These figures are used later to calculate the additional employment produced by the technologies and pathways.

5.2.7 Limitations of the DECC pathways

This subsection aims to identify some of the limitations of using the DECC pathways data to illustrate the impact of technical change on construction employment and, where possible, identifies methods to remedy these problems.

The pathways produced using the DECC model have many advantages, not least the knowledge that they meet the required carbon reduction targets. In addition, the advantages include a consideration of a wide range of technologies and the need to balance supply from the various proposed technologies. Finally, the costings provided by DECC allow for a common and consistent basis for generating the potential employment consequences of each of the pathways.

However, there are some limitations, for example the DECC central point cost estimates for each pathway do not completely incorporate the impact of 'learning curves' that could reduce costs for widely adopted technologies. Learning curves are defined as a way of documenting and predicting the process whereby experience and R&D make processes and technologies more efficient. There is evidence that the learning curves that reduce the cost of solar power and other technologies may be greater than expected (Farmer and Lafond, 2016) and would reduce the labour component of the costs. However, importantly, there is also evidence that other technologies, especially nuclear power, can increase in cost with experience (Grubler, 2010), especially if you factor in decommissioning and waste disposal, which could potentially be problematic for some of the DEC 2050 pathways.

The idea that products become cheaper as they are produced in greater quantities and mature is quite established (Farmer and Lafond, 2016). This would suggest that the more plentiful photovoltaic installations would have better learning curves than the rarer and larger nuclear power stations. However, there are practical problems in assuming rates of learning and productivity increases for renewable and other energy measures (Söderholm and Sundqvist, 2007), not least the confusion of productivity increases and technological learning curves which could easily lead to the double counting of the effects. Even focusing on a single technology predicting future learning curves is very difficult (Lindman and Söderholm, 2012).

To address these problems, the possible learning curves will be partially accounted for in the forecast method by examining the impact of improvements in construction productivity. Since construction productivity provides a large part of the benefits expected from learning curves it is important not to double count the impacts of learning curves and productivity increases. This is not an ideal approach as it would be preferable to have detailed learning curves for each technology, with details of the labour saving component of the learning curves. However, such detailed forecasts for technical change innovation are not available and productivity increases remain a useful proxy.

Each of the costed pathways has been analysed separately here. In practice, as policy develops it is likely to be a mix of each of the pathways, as Government intervenes to change regulations and subsidies in response to developments. At the same time, companies will respond to the regulated markets with their own pattern of investments. Similarly, consumers will invest in efficiency measures and distributed micro-renewables in response to price signals. Therefore, developing specific policy to assist the LCT is as complex as the technical options are, although, the nuclear / no nuclear debate is likely to continue in the face of high capital costs and relative inflexibility of supply (Fox, 2010).

Another important issue is that, in addition to not forecasting the numbers involved in each pathway, the DECC 2050 approach also does not forecast the occupations involved. Therefore, to address these problems with the DECC pathways, the thesis aims firstly to produce general employment forecasts on the basis of each of the four pathways and the technologies they involve. Then to produce forecasts of the probable occupational breakdown, again based on the technologies involved in each pathway. Finally, to develop and apply a concept of bottleneck occupations which allow forecasts of possible occupational shortages in the future.

5.3 Forecasting technical change employment

This section examines the methods used to translate the future cost estimates for each of technology proposed to achieve the LCT into estimates of construction headcount and the type of labour and skills that will be required by the various pathways. As such, the section starts by providing critical variables and the data that will be used in the forecasts. The section has been broken down into a series of stages, which are:

- Labour intensity by type of construction activity
- Construction productivity
- Using the DECC pathways to forecast employment
- The limitations of the DECC 2050 pathways

5.3.1 Labour intensity by construction subsector

This subsection aims to provide a method of translating levels of construction activity driven by technical change into levels of construction employment in a robust way.

The relationship between the value of construction activity and the number of people employed in the sector is critical to any approach that uses the cost of construction as a common metric across the wide range of low-carbon technologies. Unfortunately, this relationship between overall expenditure and employment is difficult to calculate at the level of disaggregation used by the DECC 2050 pathways. The main problem is that for different subsectors and regions, as well as for different stages of the business cycle, differing proportions of total output goes to employees. Equally, the average gross incomes of employees vary by subsectors and regions, as well as, to some degree, by the stage of the business cycle. This means that the relationship is not stable across time or type of construction. However, it is possible to use a combination of the Labour Force Survey and the Annual Business Survey (ABS) to obtain a disaggregation of output allocated to employment to two-digit SIC 2007 construction subsectors. This is useful as the LFS can then be used to expand the depth of the analysis to a more detailed level. This allows a classification of the labour intensity of construction subsectors at a level that is consistent with the view of main contractors commonly used in the industry.

The most recent ABS data at the time of writing was from 2013 and this provides the level of disaggregation provided in Table 5.4. This shows the relative proportion of each subsector's turnover that is allocated to employment costs.

Table 5.4: Employees, Goods and Gross Value Added (GVA) as a proportion of Turnover, 2013

	Employment costs (£m and %)	Purchases of goods and services (£m and %)	Approximate GVA (£m and %)	Total Turnover (£m and %)
41 Construction of Buildings	£9,955 13.2%	£48,691 64.8%	£26,715 35.5%	£75,150 100.0%
42 Civil engineering	£7,541 18.8%	£27,407 68.3%	£12,953 32.3%	£40,123 100.0%
43 Specialised construction activity	£17,539 21.9%	£46,084 57.5%	£34,248 42.7%	£80,152 100.0%
F Construction	£35,035 17.9%	£122,181 62.5%	£73,916 37.8%	£195,425 100.0%

Source: Own Analysis of Annual Business Survey data

Importantly, employment costs, purchases of goods and service and gross value added (GVA) do not necessarily sum to the total turnover. This apparent discrepancy reflects some employment costs within purchases and the approximate nature of the GVA calculations. Using this analysis of the data obtained, it is then possible to calculate details of the average gross weekly earnings of employees by construction subsector and the numbers employed by each subsector from the Labour Force Survey. This, in turn, allows an estimate to be made of the annual expenditure on employees by the subsectors as shown in Table 5.5.

The next step in the methodology to forecast the impact of technical change on construction is combining the ABS turnover and employment costs data and LFS derived employment cost and employment numbers data. This allows comparisons of the percentage of construction subsector turnover allocated to employment. This comparison is shown in Table 5.6.

Table 5.5: Weekly, Annual and Sectoral Earnings from LFS, 2013

	Average Gross Weekly Earnings	Standard Deviation	Annual Gross Earnings	Implied sector expenditure on employees
Construction of Buildings	£538.99	337.57	£28,027.61	£12,262,900,377
Construction of Roads and Railways	£593.46	265.59	£30,859.97	£2,775,275,958
Other Civil Engineering	£651.04	385.01	£33,854.20	£5,568,278,937
Electrical Installation	£530.24	283.70	£27,572.32	£4,315,213,123
Plumbing Heating & heat-pumps	£462.63	239.02	£24,056.78	£3,101,080,853
Building completion & fitting out	£431.84	231.16	£22,455.48	£3,607,135,792
Other Specialised Construction Activities	£516.81	271.86	£26,874.37	£2,373,376,785
Total	£533.24	313.593	£27,728.35	£34,003,261,825

Source: Own Analysis of the 2013 Annual Labour Force Survey

Table 5.6: Percentage of Construction Turnover Allocated to Employment

	Percentage Based on LFS	Percentage Based on ABS
Construction of Buildings	16.3%	13.2%
Civil Engineering	20.8%	18.8%
Specialised Construction Activity	16.7%	21.9%
All Construction	17.4%	17.9%

Source: Own Analysis

The differences in terms of the allocation to employment between the LFS and ABS data can possibly be explained on the basis of supply and fit contracts. Supply and fit contracts are widespread and would appear in the accounts of construction of the building and civil engineers as a goods or service purchases and have no employment content. These supply and fit contracts reduce the proportion of turnover allocated to employment in the construction of buildings and civil engineering and increase it in the specialised construction activity sectors. The pattern in the data, shown in Table 5.6, is consistent with this analysis and importantly the overall construction figures for the two approaches are comparable. The impact of supply and fit contracts suggests that the LFS based allocation is more accurate. As a result, the percentage of turnover allocated to employment and the derived labour intensity figures based on the LFS are more reliable. The thesis therefore uses the proportions from the LFS. Using the LFS based approach means that it is also possible to produce conversion factors that divide overall construction expenditure by the number of jobs created at a more detailed level, producing the labour intensity figures as shown in Table 5.7.

Table 5.7: Labour Intensity of Turnover Conversion Factors, 2013

	LFS and ABS Based	ABS Based
Construction of Buildings	--	£171,760
Civil Engineering	--	£157,710
Construction of Roads and Railways	£148,401	--
Other Civil Engineering	£162,800	--
Specialised Construction	--	£149,996
Electrical Installation	£164,963	--
Plumbing Heating & heat-pumps	£143,930	--
Building completion & fitting out	£134,349	--
Other Specialised Construction Activities	£160,787	--
Total	--	£159,362

Source: Own Analysis

These calculations are used in this chapter to provide employment estimates for each of the technologies and low-carbon pathways and in Chapter 6 to examine the employment impact of building additional houses and the necessary adaptation measures to address the flooding impacts of climate change.

Problems with the labour intensity estimates

These labour intensity estimates are average figures and, unfortunately, it is probable that there is wide variation within the categories, as indicated by the standard deviations in Table 5.5. A further problem is that the category of most interest in terms of examining low-carbon employment, 'other civil engineering', has the largest standard deviation. This means that it is possible that particular technologies adopted to achieve the transition will use more expensive 'other civil engineering staff' while others will use less expensive staff. In turn, this could mean that the technology would be employing fewer or more staff than the average figures produced in the technical-change driven forecast, given the range of potential technologies involved

Another problem is that there is little scope for differentiating the employment consequences of technologies. Technologies with high material costs could have over-estimated employment consequences and technologies with high labour costs could have under-estimated employment outcomes. Without detailed information about each technology, which is often not available, or not available in a consistent form, accurate technology-specific employment estimates are not possible.

Despite these cautions, the estimates produced for Table 5.7 are the best estimates available and, as such, are used later to convert construction activity forecasts into construction employment forecasts, in Section 5.5 and later in Chapter 6.

Details of the mapping of the construction activity statistics derived categories and the DECC 2050 Pathways categories are contained in Annexes B1 to B4.

Another consideration when forecasting construction employment is that the sector is notorious for relatively low levels of productivity growth (Abdel-Wahab et al., 2008) and this could impact on the LCT. However, there have been persistent problems with construction productivity measures (Abdel-Wahab et al., 2008). This is one of the reasons that the ABS data has been selected as the basis for the calculation of labour intensity, as other sources do not align well with the LFS data or have serious questions over their reliability (UK Statistics Authority, 2014). Other measures of construction productivity have been suggested including Total Factor Productivity (TFP) (Crawford and Vogl, 2006), but all these alternative methods are stymied by poor underlying data. As a result, the forecast productivity figures from Chapter 4 will be used later in the chapter to modify the raw labour forecasts to account for the impact of technical innovation on the LCT.

5.3.2 Using the DECC pathways to forecast employment

This subsection covers the methodology applied to produce new forecasts of the impact of technical change as a result of the LCT. It aims to explain the way in which the DECC 2050 pathways are used as the basis to produce forecasts of construction employment and occupational breakdowns, as a result of future technical change.

The first step of the methodology involves the production of a series of simplified spreadsheet models of the various potential DECC pathways to decarbonisation by 2050 (DECC, 2010; DECC, 2012). The spreadsheets contain details of the technical options associated with each pathway. The objective here is not to validate these pathways or to choose one over the others. However, the ambition is to illustrate the scale of the consequences of different technical choices on the UK labour requirements of meeting the LCT. To achieve this, DECC's central point costing for the pathways are used in an analysis to derive additional construction activity, which is then translated into additional construction employment in a further analysis. The pathways are sufficiently detailed to provide confidence in them and allow the construction specific elements to be distinguished.

The technical change forecast methods

The additional labour consequences, by technical pathway, are simply calculated by subtracting the 2014 capital costs from the later costs, as it is assumed that the 2014 costs are included in the baseline forecast pathway produced in Chapter 4. The resulting additional costs are then converted into employment figures based on the 2014 ratio of employment to construction activity, together with the ABS and LFS based estimates of construction labour intensity produced in subsection 5.3.1. These figures are then modified to take account of productivity growth.

This conversion assumes that the capital costs of the pathways translate directly to construction activity. This assumption is reasonable for most of the categories within the DECC pathways, as the capital investment needs to be built or installed in a building by a construction worker. However, some important components regarding overall costs are not in this category, for instance low-carbon transport equipment and, therefore, these are excluded from the following calculations.

Section 5.4 will provide a brief description of the key features in terms of employment for each of the pathways. This will be followed by a qualitative assessment of the key occupations and the possibilities of shortage occupations. Then section 5.5 will provide quantitative and qualitative forecasts of potential bottleneck occupations.

5.3.3 Forecast employment by pathway

This subsection aims to use the data and methodology outlined previously in the chapter to produce forecasts of the impact of the four selected DECC 2050 pathways on construction employment.

The method involves a sequence of steps. The first step derives the total additional employment impact from the total net additional 2014 cost of each pathway, divided by appropriate conversion factors for each technology obtained in Sub-section 5.3.1. The net costs are then derived by subtracting the 2014 costs from Sub-section 5.3.3 from DECC predicted annual costs. Finally, the impact of productivity gains, and learning curves established in Sub-section 5.3.4, are used to modify the forecasts to take these factors into account.

A fuller discussion of the policy consequences of these results is contained in Chapter 7.

The costs associated with the DECC 2050 pathways are reported at five year intervals. Therefore, in order to get a continuous series these were interpolated using the Stata ‘csipolate’ function. The elements that were clearly the responsibility of the construction sector were analysed. Using the construction subsector specific conversion factors these total construction costs were then translated into construction employment, then the impact of productivity gains was separately calculated

Table 5.8: Summary Additional Construction Employment by Pathway without impact of productivity 2015 and 2050

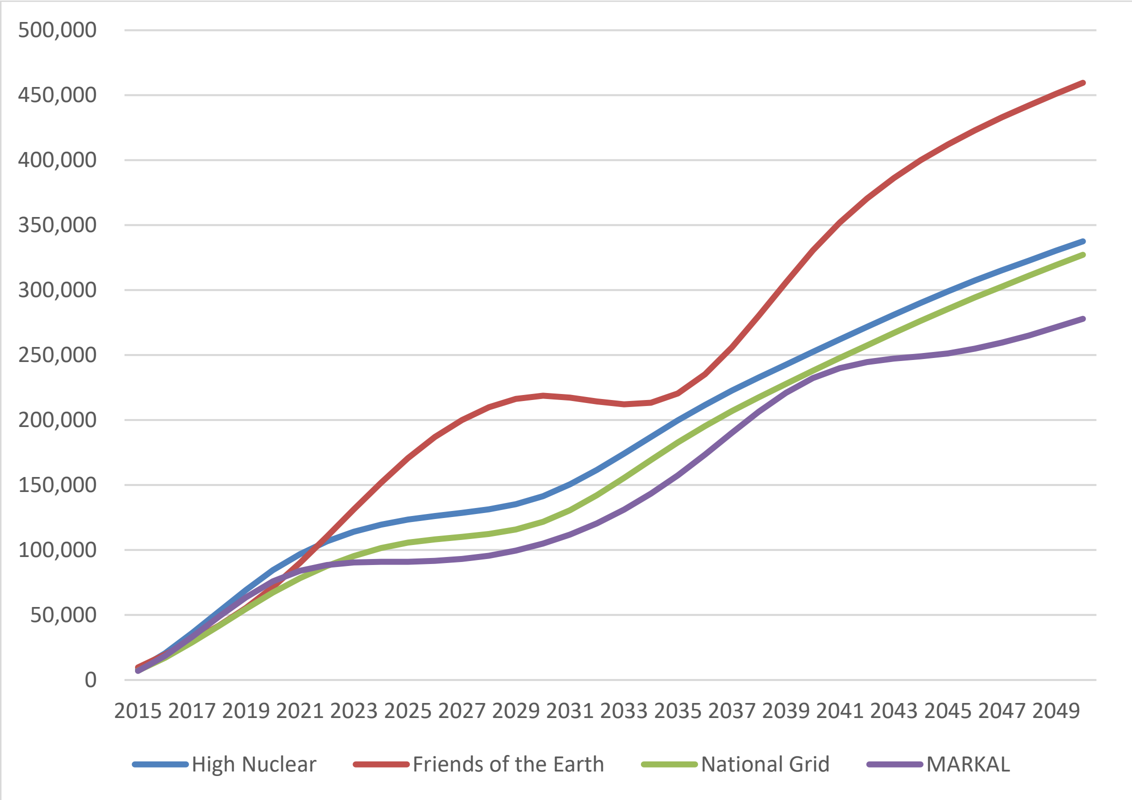
	2015	2050
DECC High Nuclear	8,011	300,663
FOE High Renewables	9,696	371,671
National Grid	6,549	298,280
DECC MARKAL	6,263	274,936
Underlying construction	2,179,453	2,333,833

Source: Own Analysis of DECC Pathways data

Table 5.8 shows that for all the pathways additional employment is much larger in 2050 than now. Clearly, the required growth in the construction workforce reflects the size of the required investment in energy infrastructure (Bolton and Foxon, 2014). Indeed, Friends of the Earth have maintained that their energy strategy has the additional benefit in creating a large number of good jobs (Green New Deal Group, 2013) and the analysis bears out their claims. It is reassuring that the analysis reveals that the MARKAL pathway, which is meant to be optimised for least costs, generates the least employment.

Figure 5.1 shows the calculated impact of taking account of the productivity increases forecast for the whole economy, in Chapter 4, for each pathway on top of the underlying growth. The impact of the forecast business cycles on underlying construction is shown. It is assumed that the contributions to overall employment from the DECC pathways are not impacted by these business cycles. There may be benefits in pulling forward the low carbon investments leading to a shallower pattern of growth. Equally, there are benefits of using infrastructure investments to smooth out the impact of the business cycle on underlying construction activity and employment. These additional policy options are explored in more detail in Chapter 6.

Figure 5.1: Additional Construction Employment by DECC Pathway, 2015-2050



Source: Own analysis

Over the longer term, these small productivity increases have significant impact on the required construction employment. However, given the problems measuring construction productivity with the available data, it is difficult to know whether these assumed productivity increases are plausible or not. Nevertheless, since the DECC costs only assume modest benefits from learning curves, the productivity increases shown, to an extent, include the potential benefits from experience and technical improvements over the period. Clearly, some individual technologies are more likely to benefit from learning curves than others. For example, various studies have suggested significant reductions in costs for offshore wind power (BVG Associates, 2015) and solar photovoltaics (Farmer and Lafond, 2016). However, the impacts of learning curves need to be distinguished from other factors such as scale or location that can also impact on costs (Lindman and Söderholm, 2012). To avoid double counting, and provide a technology neutral impact, the productivity increases have been chosen to simplify matters to produce the technical-driven employment forecast. It is probable that some technologies will have greater productivity/learning benefits leading to a reduced employment demand. However, as future learning curves and productivity are not certain, and the extent of any impact is less certain, the choice of a common productivity approach is preferable. This is especially the case as many economic forecasts suggest that a pattern of ‘secular stagnation’, or a prolonged period of low growth following a recession, has set in (Gordon, 2016) and growth is likely to remain subdued (Das, 2016).

Overall, the pattern of growth in construction employment in all the pathways is gradual and, as such, should be sustainable even if it represents a rebalancing of the economy towards construction and away from other sectors. Although financially the pattern is sensible, in terms of the labour market it is unclear what happens to construction employment demand after 2050, once the efficiency targets and low-carbon generation capacity has been installed. However, there will need to be a replacement of ageing generation capacity and there will probably also need to be updating and refurbishment of efficiency measures. However, despite this, there is likely to be a fairly rapid drop in construction activity post 2050, which would have a similar impact on construction employment. This suggests that bringing forward some of the investments could reduce the peak of construction employment and underlines the need for adequate policy and timely decision on the technical choices the government makes to achieve the LCT. This would ease the recruitment problems towards the end of the pathway as there would be more certainty of future employment.

5.3.4 Scale and the impact on skill demand and occupations

This subsection aims to discuss the impact of the scale of individual construction sites on the supply of and demand for specific skills. The size of individual projects has an important impact on the supply of skills and pattern of skill needs. This, in turn, has implications as to whether a particular technical pathway might lead to skill bottlenecks or not. Large sites are less likely to get all their workers from their locality. This lack of local supply means that there will be a need for a mobile workforce, which could add to the potential skills supply problems. Large construction sites are also linked to industrial relations problems (Gall, 2012), which too can delay projects.

The problems induced by scale will be felt most by the high-nuclear pathway, as just one of the proposed reactor builds will represent the largest individual construction project in the country. In addition, the skills required by nuclear new-builds i.e., concreters, reinforcement installers, pipefitters and high integrity welders, are such that they can only be drawn from builders of other large infrastructure projects (Construction Skills, 2011). This adds to the other skill problems associated with the high-nuclear pathway and the potential for skills shortages and bottlenecks to arise. Potential skills 'bottlenecks' in the four pathways are examined in more detail in Section 5.4.

5.3.5 Forecasts of occupational groupings by pathway

As previously stated, there is no occupational information associated with the DECC pathways and therefore it is difficult to obtain details of the occupations associated with each low-carbon technology. This means that it is difficult to predict the occupational implications of the various pathways. However, it is possible to elicit details of the type of contractor associated with each low-carbon technology. It is then possible from the LFS to obtain occupational details of sub-sectors of the construction sector, as shown in Table 5.9

The analysis in Table 5.9 shows that the different subsectors have quite different occupational profiles. As might be expected, the electrical installations and plumbing, heating and heat pumps sectors are dominated by skilled trades. Less obviously, construction of roads and railways is dominated by unskilled workers and "other civil engineering" has the most professionals and associate professionals.

Table 5.9: Occupational Group by Type of Construction Activity (Numbers), 2015

		Managers and Admin	Professionals and Associate	Skilled Trades	Unskilled	Total
Construction of buildings	(n)	52,727	112,707	330,319	131,059	626,812
	(%)	8.4%	18.0%	52.7%	20.9%	100.0%
Construction of roads & railways	(n)	7,752	31,613	15,902	56,512	111,779
	(%)	6.9%	28.3%	14.2%	50.6%	100.0%
Other civil engineering	(n)	14,601	76,137	40,893	32,724	164,355
	(%)	8.9%	46.3%	24.9%	19.9%	100.0%
Specialised construction activities	(n)	10,961	11,720	65,153	52,053	139,887
	(%)	7.8%	8.4%	46.6%	37.2%	100.0%
Electrical installation	(n)	15,064	28,542	130,787	13,684	188,077
	(%)	8.0%	15.2%	69.5%	7.3%	100.0%
Plumbing heating & heat-pumps	(n)	14,414	20,244	144,378	10,538	189,574
	(%)	7.6%	10.7%	76.2%	5.6%	100.0%
Building completion and fitting out	(n)	25,263	23,705	387,354	51,912	488,234
	(%)	5.2%	4.9%	79.3%	10.6%	100.0%
Total	(n)	140,782	304,668	1,114,786	348,482	1,908,718
	(%)	7.4%	16.0%	58.4%	18.3%	100.0%

Source: Own Analysis of 2015 Annual Labour Force Survey

Once the sub-sectoral pattern has been established, it is then possible to allocate for each technology within the pathways a percentage breakdown by sub-sector and then calculate the total occupational structure for each pathway. This methodological profiling of the various technologies in terms of the construction subsectors responsible for delivering the LCT is detailed in Annex C. The profiles were developed on the basis of an understanding of the construction sector and low-carbon technologies (Jagger, 1998; Jagger and Connor, 1998; Jagger, 2006; Jagger 2008; Jagger 2009). The profiles were then subsequently validated by three industry experts, a quantity surveyor who worked on the building of Heysham nuclear reactor and other large civil engineering projects, a National House Building Council (NHBC) inspector with experience of domestic and commercial buildings and renewables, and a civil engineer with experience of industrial and energy infrastructure projects.

These breakdowns were then used to generate a cost breakdown of each pathway in 2015 and 2050 by construction subsector. Tables 5.10 to 5.13 show the results of such calculations and indicate that, broadly, each of the pathways has a similar occupational profile. The details of the sub-sectoral breakdown of each technology is contained in the Annex tables B1 to B4. The only major divergence is within the Friends of the Earth pathway, which has more professionals and associate professionals and fewer skilled trades. Overall, all the pathways have more professionals and associate professionals and fewer unskilled than the construction sector as a whole. This reflects the greater civil engineering component of the technical pathways that will address the LCT.

Table 5.10: High Nuclear Subsector Additional Employment Breakdown in 2015 and 2050

High Nuclear	2015		2050	
	(n)	(%)	(n)	(%)
Construction of buildings	800	10.1%	38,100	12.7%
Construction of roads and railways	**	0.1%	-100	0.0%
Other civil engineering	2,200	28.0%	28,100	9.3%
Specialised construction activity	800	9.9%	37,600	12.5%
Electrical installation	1,200	15.1%	77,500	25.8%
Plumbing heating & heat-pumps	2,600	32.4%	107,800	35.9%
Building completion and fitting out	300	4.3%	11,600	3.9%
Total	8,000	100.0%	300,700	100.0%

Source: Own Analysis, Notes: Values rounded to the nearest 100 and values less than 100 supressed

Table 5.11: Friends of the Earth Subsector Additional Employment Breakdown in 2015 and 2050

FoE	2015		2050	
	(n)	(%)	(n)	(%)
Construction of buildings	-300	-2.7%	7,900	2.1%
Construction of roads and railways	100	0.6%	**	0.0%
Other civil engineering	3,900	40.6%	69,800	18.8%
Specialised construction activity	1,800	18.8%	34,400	9.3%
Electrical installation	1,800	18.9%	174,200	46.9%
Plumbing heating & heat-pumps	2,600	26.5%	86,500	23.3%
Building completion and fitting out	-300	-2.6%	-1,100	-0.3%
	9,700	100.0%	371,700	100.0%

Source: Own Analysis, Notes: Values rounded to the nearest 100 and values less than 100 supressed

Table 5:12 National Grid Subsector Additional Employment Breakdown in 2015 and 2050

	2015		2050	
	(n)	(%)	(n)	(%)
Construction of buildings	387	5.9%	28,870	9.7%
Construction of roads and railways	19	0.3%	-35	0.0%
Other civil engineering	2,209	33.7%	29,304	9.8%
Specialised construction activity	682	10.4%	24,351	8.2%
Electrical installation	995	15.2%	81,054	27.2%
Plumbing heating & heat-pumps	1,912	29.2%	123,122	41.3%
Building completion and fitting out	345	5.3%	11,615	3.9%
	6,549	100.0%	298,280	100.0%

Source: Own Analysis, Notes: Values rounded to the nearest 100 and values less than 100 supressed

Table 5:13 MARKAL Subsector Additional Employment Breakdown in 2015 and 2050

	2015		2050	
	(n)	(%)	(n)	(%)
Construction of buildings	470	7.5%	27,529	10.0%
Construction of roads and railways	8	0.1%	-174	-0.1%
Other civil engineering	2,049	32.7%	29,681	10.8%
Specialised construction activity	608	9.7%	27,828	10.1%
Electrical installation	1,072	17.1%	60,594	22.0%
Plumbing heating & heat-pumps	1,712	27.3%	117,862	42.9%
Building completion and fitting out	345	5.5%	11,615	4.2%
	6,263	100.0%	274,936	100.0%

Source: Own Analysis, Notes: Values rounded to the nearest 100 and values less than 100 supressed

These subsector profiles can then be translated into detailed skill profiles using a shift-share approach (Stevens and Moore, 1980). This process maintains the occupational profiles of each subsector, while taking account of the proportions of each subsector linked with each technology as well as the capital costs of each technology within each pathway. This method of analysis results in the occupational profiles for each pathway shown in Table 5.14.

Table 5.14: Specific Occupational Profiles by Pathway, 2050

2050	Nuclear	Friends of the Earth	National Grid	MARKAL
Production managers in manufacturing	6,400	9,400	6,900	6,100
Production managers in construction	12,000	13,900	11,100	10,300
Other Managers and Directors	11,500	15,700	11,200	10,200
Civil Engineers	--	7,500	--	--
Construction Project Managers	--	4,033	--	--
Other Professional Occupations	27,800	32,500	28,000	25,900
Associate Professional & Technical Occupations	13,800	19,700	13,600	12,600
Bookkeepers and Payroll Managers	4,300	4,600	4,200	--
Other Administrative Occupations	7,100	8,300	7,000	6,500
Personal Assistants	--	4,300	--	--
Other Admin, Secretarial Caring and Sales	12,600	13,300	12,700	15,500
Air Conditioning and Refrigeration	6,400	5,100	7,300	7,000
Electricians and Electrical Fitters	40,400	86,300	42,100	32,300
Telecommunication Engineers	5,400	11,900	5,700	4,400
Electrical and Electronic Trade n.e.c.	4,100	7,800	4,300	3,400
Bricklayers and Masons	7,500	5,400	5,100	5,500
Plumbers and Heating and Ventilation	62,700	50,300	71,400	68,300
Carpenters and Joiners	13,000	8,000	9,900	10,400
Construction and Building Trades n.e.c.	9,700	4,100	8,000	7,800
Construction and Building Supervisors'	4,200	5,000	--	--
Other Skilled Trades Occupations	18,300	17,400	21,400	24,100
Scaffolders and Stagers	5,200	4,700	--	--
Mobile Machine Drivers	--	4,600	--	--
Other Process Plant and Operatives	13,400	11,4020	14,900	15,400
Elementary Construction Operatives	10,700	10,200	9,400	21,600
Other Elementary Occupations	4,100	6,100	4,100	**
Total	300,700	371,700	298,300	274,900

Source: Own Analysis

*Note: ** values supressed as less than 4,000, all estimates rounded to the nearest 100*

The results show that each pathway has a remarkably similar skills profile, despite the varying technology mixes employed. Some features, however, stand out. For instance, the Friends of the Earth pathway requires significantly more Civil Engineers and Electricians than the other pathways, while the National Grid pathway requires more Plumbers and Heating and Ventilation skilled trades.

5.4 Suspected bottleneck occupations

Forecasting future skills shortages is difficult, but has been of policy interest especially in the context of migration policy (Grieg et al., 2008). This means that most of the measures of skills shortages have been developed in the context of debates over migration. Within a report for the New Zealand Department of Labour aimed at identifying occupations to allow into the country, Infometrics Ltd proposed a measure based on occupational specialisation that could be linked to skill shortages.

> *"...measures of occupational specialisation, or conversely measures of the substitutability of workers between occupations can provide an indication of the occupations that are likely to be more susceptible to skill shortages than others. That is, a highly specialised occupation has a greater potential to experience skill shortages than an occupation that can draw on candidates with a wider range of qualifications. The length of time to undertake the specialised training will also have an impact on the time it will take to resolve skill shortage problems." (Infometrics, 2006: 16-17)*

This idea becomes the basis for the concept of bottleneck occupations that might cause skills shortages in the future. These bottleneck occupations are the focus of this section, which starts by defining the concept.

5.4.1 What are skills bottleneck occupations

In addition to the quantitative methods used in the thesis to forecast the number of construction workers required to implement the LCT, this section aims to introduce the concept of ‘bottleneck occupations’ as a mixed-method of characterising occupations that might develop debilitating shortages and disrupt the LCT. The concept is sometimes known as bottleneck vacancies or hard to fill vacancies (Attström et al., 2014).

It is difficult to identify existing low-carbon labour. The difficulty is mainly because workers constructing low-carbon infrastructure and dwellings have the same characteristics and, often, the same training and job-title as those building other forms of infrastructure and dwellings. As such, it is only possible to characterise the proportion of the workforce that is working on low-carbon projects, rather than whole numbers in occupations that can be considered low-carbon. A further problem is that the most likely method for improving the productivity of the sector will be through reducing the amount of skilled labour required either by making the process possible with unskilled labour or reducing the time needed to perform certain procedures. Given the wide variation in construction productivity, this will often mean moving the laggards up to best practice (Proverbs et al., 1999). This means that the construction skill mix is likely to change in the future and the patterns are, therefore, not easily predicted.

However, it is possible to characterise some of the specialised labour that could cause problems if significant shortages were to emerge. There are already a series of construction occupations that are considered to be in shortage by the Migration Advisory Committee (MAC), for example, electricity grid linesmen and electricity substation engineers (Migration Advisory Committee, 2009). These occupations require relatively long periods of training and experience before becoming competent. However, the long training periods alone are not sufficient to cause shortages. The pattern of demand needs to be erratic and unpredictable. This leads to employers and individuals being unwilling to risk investments in training. In effect it is this combination of long training and uncertain demand that leads to the potential for occupational skills shortages, which this thesis terms as ‘bottlenecks’. So, if potential skills problems for the LCT are to be identified, these occupational features need detailed examination.

Another key feature of bottleneck occupations is that the occupation needs to be so specialised and small that there is no significant pool of potential labour that can pulled in to undertake the required work. This feature, almost automatically, causes problems for labour market analysts as, typically, occupational categories in the official statistical collections are relatively large. This means that bottleneck occupations created by shortages in specialised skills areas do not usually appear as a distinct category in the Standard Occupational Classification (SOC2010) which is used to classify job titles into statistical categories.

However, the statistics do allow the identification of occupations that are sufficiently large that bottlenecks are unlikely to occur. The first step towards identifying bottleneck occupations is to use the labour Force Survey (LFS) to identify the construction occupations that will not become bottlenecks due to plentiful supply. Then by collating four LFS surveys some potential bottleneck occupations are identified. Finally, as most bottlenecks are too specialised to figure in the official statistical classifications and data collection, a qualitative analysis of other potential bottlenecks is undertaken. These analyses are detailed in Section 5.4.3.

This section uses quantitative and qualitative analysis to examine the possibility of bottleneck occupations emerging that could disrupt the progress of the DECC pathways.

5.4.2 Construction occupations immune from bottlenecks

Using the Labour Force Survey (LFS) it is possible to identify those four-digit Standard Occupational Classification (SOC) occupations with more than 10,000 reported working in the construction sector (See Table 5.8). This is the cut off for reporting on one quarter's LFS. The figures have also been rounded to the nearest 100 to reflect their origin in a sample survey in line with Office of National Statistics (ONS) guidance. These occupations, given their scale, are unlikely to generate bottlenecks for individual projects and are likely to be able to scale up to meet the potential demand from a programme of projects.

Table 5.15: Larger Occupations within the Construction Sector

SOC Code	Description	(n)	(%)
1122	Production managers and directors in construction	113,100	5.2
1251	Property, housing and estate managers	10,300	0.5
1259	Managers and Proprietors in other services n.e.c.	11,000	0.5
2121	Civil engineers	36,800	1.7
2433	Quantity surveyors	26,200	1.2
2434	Chartered surveyors	10,200	0.5
2436	Construction project managers and related professionals	44,100	2.0
3114	Building and civil engineering technicians	14,500	0.7
3531	Estimators, valuers and assessors	12,000	0.6
3545	Sales accounts and business development managers	19,100	0.9
4122	Book-keepers, payroll managers and wages clerks	28,900	1.3
4159	Other administrative occupations n.e.c.	40,900	1.9
4215	Personal assistants and other secretaries	21,800	1.0
5223	Metal working production and maintenance fitters	26,100	1.2
5225	Air-conditioning and refrigeration engineers	13,600	0.6
5241	Electricians and electrical fitters	144,400	6.6
5242	Telecommunications engineers	16,200	0.7
5249	Electrical and electronic trades n.e.c.	15,700	0.7
5312	Bricklayers and masons	69,600	3.2
5313	Roofers, roof tilers and slaters	35,600	1.6
5314	Plumbers and heating and ventilating engineers	141,400	6.5
5315	Carpenters and joiners	200,500	9.2
5316	Glaziers, window fabricators and fitters	20,200	0.9
5319	Construction and building trades n.e.c.	208,800	9.6
5321	Plasterers	47,200	2.2
5322	Floorers and wall tilers	36,700	1.7
5323	Painters and decorators	88,900	4.1
5330	Construction and building trades supervisors	39,000	1.8

Source: Own Analysis of the LFS October to December 2015

Using an annual LFS dataset, which combines four quarters, it is possible to identify occupations down to 6,000 people employed. Table 5.16 provides a listing of smaller construction sector occupations with between 10,000 and 6,000 people. This range includes occupations significant enough to be important, but small enough to potentially produce bottlenecks. Generic occupations found across many sectors such as project managers can be excluded as there is scope for movement between sectors, negating any bottleneck. Finally, there are some elementary occupations, which as the name suggests require little or no training and are therefore not going to become bottleneck occupations.

Table 5.16: Analysis of Smaller Construction Occupations

SOC code	Description	Const-ruction (n)	% of Const-ruction	All Sectors (n)	% in Const-ruction
1132	Marketing and sales directors	8,553	0.4	200,219	4.3
1251	Property, housing and estate managers	8,122	0.4	179,885	4.5
1259	Managers and Proprietors in other services n.e.c.	10,818	0.5	206,460	5.2
2129	Engineering professionals n.e.c.	10,928	0.5	96,017	11.4
2424	Business and financial project management professionals	6,252	0.3	192,113	3.3
2431	Architects	6,239	0.3	54,982	11.3
2434	Chartered surveyors	8,592	0.4	58,416	14.7
3234	Housing officers	6,725	0.3	50,761	13.2
3531	Estimators, valuers and assessors	9,465	0.4	63,078	15.0
3539	Business and related associate professionals n.e.c.'	6,565	0.3	137,984	4.8
3541	Buyers and procurement officers'	6,001	0.3	70,890	8.5
5215	Welding trades'	8,060	0.4	70,775	11.4
5216	Pipe fitters'	6,398	0.3	14,971	42.7
5311	Steel erectors'	6,764	0.3	12,860	52.6
8211	Large goods vehicle drivers'	9,834	0.5	293,359	3.4
9139	Elementary process plant occupations n.e.c.'	10220	0.5	86,613	11.8
9260	Elementary storage occupations'	9288	0.4	438,280	2.1

Source: Own Analysis of 2015 Annual LFS

However, a number of SOC 2010 occupations remain where the numbers in construction are too few to report in the LFS analysis and where there are relatively few of them outside of construction. These potentially could be bottleneck occupations. These are:

- Chartered surveyors
- Housing officers
- Estimators, valuers and assessors
- Welding trades
- Pipe fitters
- Steel erectors

The last three are particularly linked to some low carbon technologies. These have also been identified as being at risk by the more qualitative methods adopted by the Migration Advisory Committee. The following sub-sections provide qualitative analyses of the potential for disruptive skills bottlenecks by DECC pathway.

5.4.3 Bottlenecks in the high-nuclear pathway

To some extent, the potential skills bottlenecks that could affect the high-nuclear pathway have already been covered in the earlier discussion of the problems that could impact the nuclear new-build sector. Nuclear new-build requires large numbers of concreters, installers of steel reinforcement, pipefitters and high-integrity welders (Construction Skills, 2011). These critical occupations have a long training period and have, on various occasions, been identified as shortage occupations by the Migration Advisory Committee (Migration Advisory Committee, 2009; 2011). The supply of these specialist skills has not been helped by the continuing uncertainty surrounding nuclear new-builds in the UK, which deters construction workers from undertaking the lengthy and costly training.

Moreover, the civil engineering aspect of nuclear new-build requires skills that are generally more plentiful than the specialist concreters and welders. However, the demand for civil engineers to build flood and sea defences is likely to greatly increase and may pose a challenge for nuclear new-build projects. The scale of the demand for civil engineering skills associated with hard defences, such as sea walls, as adaptation to rising rainfall and sea-levels is discussed further in Chapter 6.

Therefore, combining the effects of these other demands on construction employment, if there is more than one nuclear site at the same stage of construction at the same time, the limited number of mobile and skilled workers willing to work at relatively remote sites may be smaller than the demand. Equally, once settled in the area of early nuclear sites, it will be necessary for the workforce to move to the next equally remote site. This mobility will put additional pressures on the ability to recruit and retain the necessary specialist staff for nuclear new-build.

Apart from nuclear new-build, the High-nuclear DECC pathway also requires extensive electrification of the railways and a reconfiguring of the National Grid. Both of these require people capable of working with high-voltage electricity. The Migration Advisory Committee identified high voltage line repairers and cable jointers as shortage occupations in 2011 (Migration Advisory Committee, 2011). This historic problem, combined with the future expanded requirement, could represent another potential bottleneck. Most high-voltage electricians are specialist sub-contractors, who operate in a range of areas from the national grid to rail electrification. This range of working environments makes shortages less visible in specific sub-sectors. This lack of visibility, in turn, can lead to critical shortages if all the sectors that the high-voltage electricians operate in simultaneously expand their demand.

Since all of the four DECC 2050 pathways under consideration here involve both electrification of the railways and grid restructuring, this potential shortage is likely to be a common risk for all the pathways under consideration.

5.3.4 Bottlenecks in the high-renewables pathway

When the Friends of the Earth DECC pathway is examined, the probable bottlenecks in this high-renewables pathway focus around offshore wind, installation of ground and air sourced heat-pumps, as well as ensuring the air-tightness of existing dwellings with mechanical ventilation and heat recovery (MVHR). Offshore wind construction could, to an extent, draw upon the skills within the North Sea oil industry (Esteban et al., 2011). The likelihood of an offshore bottleneck depends on the pace at which oil dependence winds down and wind power takes off. Since both of these energy technology changes are largely dependent on government policy, this highlights the need to reconcile the mutual UK skills demands when generating new policy. However, to the advantage of the LCT, the current low oil prices are releasing many people experienced at working offshore, who would be capable of working in the offshore wind industry. This process, if continued, might alleviate any potential shortages in the offshore wind industry. However, this depends on the pattern of growth of offshore wind builds matching the decline in offshore oil. Any mismatch could lead to the offshore skills being lost and skills shortages for offshore wind emerging.

Another aspect of the High Renewables DECC pathway which could potentially lead to bottlenecks is in the conversion of domestic and commercial heating to all electric, which will involve the more widespread use of heat pumps. This will require people skilled in the handling of refrigeration fluids, as well as the design and installation of the required pipes. As there are currently relatively few people available in the UK with these refrigeration skills, the expansion of the market will have to go hand-in-hand with a comparable expansion in the necessary skills. However, at present, the main training that is currently being provided is coming from equipment manufacturers (Gleeson, 2015). Limited training covering a range of heat-pump manufacturers could limit the choice of technologies being installed and, in turn, could reduce the pace of innovation and slow the adoption of this sort of technology.

The potential for bottlenecks here could be avoided if heat pumps that can simply replace existing gas-fired central heating boilers are developed. Then the existing gas fitter workforce could transition to heat pumps. This is not the optimal solution for heat pumps, which operate better using lower flow temperatures, and so cannot use existing gas-fired piping and radiators (Singh et al., 2010). In new-builds, where heating systems and dwellings are designed to benefit from heat pumps, more sophisticated systems that store heat when electricity is cheap and then release the heat when the dwelling needs heating, are possible (Arteconi et al., 2013). However, at the moment, there is not the vocational education capacity to roll out such bespoke systems (Gleeson, 2015). This all suggests that efforts will have to be made in the heat pump area to improve the training and technologies available.

The higher levels of domestic energy efficiency require mechanical ventilation and heat recovery (MVHR) systems that remove stale and damp air from kitchens and bathrooms and return fresh air having warmed it up from heat recovered from the exhaust air. These are relatively new on the UK market and this is another area where the skills will have to be built up as the market develops. Again, the main source of training in the installation of MVHR equipment comes from manufacturers. This has similar implications for innovation and range of technologies adopted as with the heat pump situation.

Domestic photovoltaics requires domestic electricians and roofing skills. However, we have seen that there is a quite large pool of these skills in the current construction workforce. These existing workers can easily acquire the additional skills needed for photo-voltaic installations. The only problem may be the current requirement for appropriate qualifications and quality systems as part of the licensing process. This issue of licensing is discussed in more detail in Chapter 6.

All these factors which could potentially create construction skills deficits could limit the choice of technologies that can be installed in the High Renewables DECC Pathway and could make the MVHR market less dynamic and successful than the LCT requires.

5.4.5 Bottlenecks in the national grid pathway

The National Grid pathway is a business led pathway. This means that the main risk in terms of skills is the lack of central coordination of training efforts. Importantly, the potential problems with rail electrification and restructuring the grid that apply to the other pathways, and have been discussed earlier, also apply here.

In contrast, the National Grid DECC pathway involves only a limited amount of nuclear power, insufficient to replace the existing capacity. The scale of the nuclear component of this pathway means that it is less likely to trigger the problems foreseen for the high nuclear pathway.

The main skills problem with this pathway is the inclusion of innovative technologies, such as carbon capture and storage (CCS) that the pathway will adopt as the construction sector often has problems providing skills for new technologies before they take off. It has been suggested that CCS will require a publicly funded delivery agency akin to the one used for the London Olympics (Oxburgh, 2016). The construction sector's low skill base means that it is it has problems with innovation (Leiponen, 2005) and such a public body might be needed. The lack of skills may provide a barrier to the rapid and early adoption of these low-carbon technologies (Gluch et al., 2009). In part, this is due to the structure of the sector, as it is known that small firms are less likely to innovate (Freel, 2005). However, this might partly be an issue of measurement, as the innovation occurs within the construction supply sectors, and the R&D and patents, are not allocated to the construction (Winch, 2003).

5.4.6 Bottlenecks in the MARKAL pathway

The final pathway to be examined in terms of potential skills shortages and bottlenecks is the DECC MARKAL Pathway. The main problem with the MARKAL pathway is the pattern of implementing little of many options, rather than the concentration on a few technology options. This implies that there is less scope for individuals to concentrate on one technology, and on the skills needed to apply the technology, in the knowledge that this will provide them with a long-term career.

Largely, the points relating to the National Grid pathway, already discussed, also apply to the MARKAL pathway. However, the MARKAL pathway puts greater emphasis on tidal stream and tidal range projects. Tidal range projects, mainly tidal lagoons, involve large-scale civil engineering and some of the issues about large localised projects that apply to nuclear power would also apply here. These sorts of projects require the mobilisation of large workforces, often distant from centres of population, which can be difficult.

5.4.7 Summary of occupational bottlenecks

The quantitative approach to identifying skills bottlenecks, summarised in Table 5.16, produced three potentially problematic occupations. These were:

- Welding trades
- Pipe fitters, and
- Steel erectors.

These occupations have also been identified by other research, including that of the Migrations Advisory Committee as potentially in critically short supply, especially for nuclear new build.

Apart from the high-renewables pathway, civil engineering skills were identified as a potential bottleneck in the other pathways. In particular, mobilising civil engineers for large-scale projects, such as nuclear new-build and tidal lagoons, could be a problem. Installers of mechanical ventilation and heat recovery (MVHR) systems, as well as installers of heat pumps, were identified as being critical for all pathways, but in particular for the high-renewables pathway. The problems the construction sector has with innovation might also impact the adoption and widespread diffusion of new technologies within all the pathways, as there is evidence that the pace of innovation is dependent on the skills and absorptive capacity of the sector (Gluch et al., 2009).

However, an overriding concern, shown in the results of the forecasts, is the growth in numbers of construction workers implied by the pathways. It is probable that the current training system does not have the capacity to supply the required numbers of skilled workers and, equally, is unlikely to be able to provide the required mix of skills. This issue is explored in more detail in Chapter 6.

5.5 Implication for the low-carbon transition

Overall, the critical message arising from the forecast produced to analyse the employment impact of technical change on construction is that the LCT will require a significant increase in the size of the sector. The implied demand is less in some of the pathways, with the High-Nuclear pathway requiring at peak 48 per cent more construction workers, the MARKAL pathway 82 percent more, the National Grid pathway 86 percent more, and the High-Renewables pathway 151 percent more, all of which are significant increases.

In terms of potential construction skills shortages that might disrupt the LCT, the analysis of potential bottleneck occupations indicates that the High-Nuclear pathway is more at risk of critical skills shortages, while the High-Renewables is least likely to experience bottleneck occupations. Overall, both the numbers required and the potential for critical skills shortages need to be better incorporated into the debates surrounding which pathway to adopt and the policies that need to be used to expedite the LCT. In response to the fifth research question: How will technological driven initiatives additionally impact on construction skills demands? This chapter has shown that the demands of the LCT in terms of technical change will create significant additional demand for construction workers and an increased demand for specific skills and occupations. The policy implications of this insight are explored in more detail in Chapter 7.

The next chapter, Chapter 6, examines the potential impact of institutional factors on the supply and demand of construction workers required to achieve the LCT and the training required to provide the probable associated skill mixes.

6 – Impact of Institutions on Low-Carbon Skills

"Confidence and clarity in long-term policy direction is vital for investment, jobs, exports and keeping costs down.

Lack of confidence may delay or stop individual projects and may also push supply chain investment overseas, permanently depriving the UK of the industrial benefits.

Lack of clarity of a future pipeline forces any investment to be short term, inhibiting cost reduction and skills development.

In the increasingly international world of energy there are great opportunities for the UK to export but these depend on the visibility of a strong and sustainable home market.

Energy projects are large. Policy stability minimises unnecessary risk, allowing lower finance costs and keeping bills down."

Siemens AG Written Evidence to House of Commons Select Committee
Energy and Climate Change Committee (2016)

6.1 Introduction

6.1.1 Aims

This chapter aims to examine the role of institutions, particularly skills institutions, in the demand for low-carbon skills and, more importantly, the supply of skills for the LCT. Policy initiatives have, in the past, made substantial impacts on the supply of specific skills groups (Borrás and Edquist, 2014). For example, government schemes to encourage the training of scientists and engineers (Roberts, 2002). Therefore, similar policy initiatives, if introduced in a timely fashion, could positively impact on the supply of skills needed for the LCT.

The chapter first examines the impact of potential policy-led initiatives that could produce additional extra demand for construction skills in the UK. This includes, the less quantified and less researched, adaptive responses to extreme weather and rising sea levels due to climate change. The chapter aims to provide forecasts of the construction skills demand consequences of this adaptation. These can then be combined with the underlying growth forecast and the four DECC pathway construction skills demand forecast to allows a potential overall demand to be derived and characterised over the next thirty-five years, the period of the LCT. This, in turn, will help to assess the capacity of the skills institutions to supply the numbers and skills demanded by the construction sector.

In addition to policy initiatives, a range of other factors will also influence the future skills supply in the construction sector. These include demographics, the attractiveness of construction as a career and the degree of certainty with which careers in construction are deemed likely to be long and fruitful. Policy was one of the three drivers of skills demand identified in the tripartite model proposed in Chapter 3. Therefore, this chapter also aims to determine the potential for other policy driven demands, unrelated to the LCT, that could compete with the transition for construction skills.

Finally, the chapter also aims to explore a range of possible and necessary policy responses which could ensure that the skills required for the LCT are provided.

6.1.2 Introductory outline

Predicting the impact of policy change on the supply of low-carbon skills is, perhaps, even more difficult than predicting the impact of technical change. Policy is often not rational or evidence based, not in the long-term interests of employers, workers, or the environment and not coherent with other policies (Richardson, 2000). Demographic and other trends can largely determine overall levels of educational attainment (Bowman, 1985; Crespo Cuarsema et al., 2014). However, the demographic and educational trends suggest that alone they will be insufficient to provide the required additional construction labour required for the LCT. Equally, it is also clear that policy initiatives can overwhelm existing trends and other drivers, especially at the level of subject choice, as shown in the later analysis of civil engineering graduates.

Given the importance of policies in ensuring that there are sufficient construction workers with the required skills to achieve the LCT it is necessary to examine at least some of the policies that might address the issues. These policies are examined in Section 6.5 of this chapter. The final section explores the impacts of policies on the Low Carbon Transition.

6.1.3 Context

Chapter 3 developed a Tripartite Model of skills demand. As stated previously, this model proposes that the demand for skills is dependent on three coevolving factors: underlying demand, technical-change-driven demand and institutional or policy-driven demand. Chapter 4 provided a long-term forecast of construction core activity, based on an economic forecast. This core activity is the first leg of the Tripartite Model. Chapter 5 then provided a series of forecasts for the potential impacts of technical change on the LCT, as laid out by DECC 2050 pathways, thus forming the second leg of the Tripartite Model. Therefore, the objective of this chapter is to provide an understanding of the impact of policy changes on skills demand which constitutes the third leg of the Tripartite Model. The three components of the proposed model need to coevolve harmoniously for skills supply to successfully meet skill demand. This coevolution suggests that LCT policy changes need to respond to the changing patterns of demand produced by both changes in technology and underlying economic growth. Equally, underlying demand and the pattern of technical change will respond to changes in policy. An example of these interactions is when advances in technology led to the rapid price reductions of solar photo-voltaic panels. This then led to reductions in feed-in-tariffs or government subsidies which, in turn, resulted in reduced installations (Muhammad-Sukki et al., 2013) impacting negatively on the transition.

In contrast, slower than expected GDP growth and a more rapid than expected adoption of LED lightbulbs, have both led to reductions in the expected electricity demand, which has resulted in energy efficiency targets being achieved ahead of targets. This positive outcome has meant that the government has not needed to introduce further policies to reduce the UK's energy consumption (Bertoldi et al., 2016).

However, policy change can also alter the pattern of demand directly, without the impact of technical or underlying change (Auld et al., 2014). Various policy initiatives have been taken in an effort to make investment in nuclear power in the UK attractive (HM Government, 2013), with all of the associated implications for construction skills (Nuclear Energy Skills Alliance, 2014). The policies surrounding nuclear power, although not directly aimed at skills issues, have profound indirect construction skills consequences. This underlines that both the indirect and direct impacts of policy changes on construction skills supply and demand need to be considered. Moreover, the degree of responsiveness of the UK's skills policy and training systems to the demand produced by any underlying changes, or by technical change, also needs to be considered to ensure that increasing demand is met.

6.1.4 Structure of the chapter

There are five further sections to the chapter. These are:

- Section 6.2 – explores the potentially conflicting additional demands for construction workers as a result of adapting to the negative impacts of climate change and other policy driven demands
- Section 6.3 – this looks at the drivers of supply of construction workers, including relevant policies, and determines whether supply will meet the level of demand
- Section 6.4 – examines the impact of the business cycle and why addressing this could be an important policy response to the demands of the LCT
- Section 6.5 – examines the 'employer-led' policies which is the UK's guiding principle for skills institutions and the potential negative impact of this approach
- Section 6.6 – examines other policy initiatives to increase recruitment of construction workers

- Section 6.7 – draws together the potential impact of institutions, and in particular skills institutions, and their policies on the LCT.

6.2 Demand and supply of construction workers

This section aims to explore the total pattern of demand of construction workers from all the identified areas as well as the drivers of the supply of construction workers over the period of the LCT. This section consists of four subsections which explore: the potential additional demand caused by policy to provide sufficient new dwellings to meet demand; the supply of construction workers on the basis of demographic trends; the problems with forecasting the supply of specific occupations and a further exploration of occupations based on qualifications with a long training period. Finally, the forecasted pattern of demand is confronted with and analysed in the context of the forecast pattern of supply.

6.2.1 Additional new build houses

A possible extra demand on the construction sector that is driven by policy unrelated to the LCT is likely to be a commitment to build sufficient new houses to address the housing shortage in the UK. There are various estimates of the size of the housing shortage, the types of dwellings that are needed to meet the demand and future patterns of household formation (Holmans, 2013). This subsection examines the demand estimates and then translates the implied costs into additional construction labour demand.

There was a political consensus at the 2015 election that there should be a target of 240,000 new dwellings per year, which is about twice the current levels (CBI, 2014). This 240,000 political consensus figure for new-builds derives from a 2007 Housing White Paper (DCLG, 2007) and a report by the Town and Country Planning Association (TCPA) (Holman, 2013). This suggested that 240,000 to 245,000 new homes would be needed to meet demand. The TCPA report identified that the additional demand would not be evenly distributed, with a quarter of all housing requirements concentrated in London and over 60 per cent in southern regions.

This implies that a similar concentration of construction workers will be needed in the South East. This will necessitate skilled construction workers moving from the North and West to build in the South-East. The need for a mobile workforce would also be driven by any reliance on large construction sites away from towns, such as nuclear new build.

In addition, there has been a collapse in public housebuilding, which has been linked to both rising house prices and rents (Jefferys and Lloyd, 2015). Constantly rising house prices also provide an incentive to private developers to delay building on the land they own as they can make more money from the land in the future (Barker, 2008). This means that the expanded new-build would most likely result from a massive expansion of public sector building.

Table 6.3 shows the scale of current supply of new dwellings and the costs of construction by housing sector. This data is used to forecast the average cost per dwelling and the implied additional construction volume and employment in order to meet the target.

Table 6.1: Additional Construction Volume and Employment from New-Build

	New Dwellings (April 2014 to March 2015)[1]	Construction Volume (£m) (April 2014 to March 2015)[2]	Cost per dwelling	Implied Additional Volume (£m) (If all new dwellings in category)	Implied Additional Employment (If all new dwellings in category)
Private	118,060	22,850	£193,546	16,947	98,667
Public	34,380	5,629	£163,729	14,336	83,465
Total	152,440	28,481	£186,834	16,359	95,243

Sources: New Dwellings (1) DCLG (2016); Construction volume (2) ONS (2016) Construction Statistics; Cost per dwelling and implied volume and employment own calculations

The dwelling mix for public sector new builds tends to be smaller and hence cheaper. Building all the additional dwellings in the public sector, using the existing mix of dwelling types, the projected costs of meeting the 240,000 homes target would be £14,336 million per year as shown in Table 6.2. By comparison, meeting the target by private sector building, and again maintaining the current mix of dwellings, the cost would be higher at £16,947 million per annum. Using the figure from Table 5.7, each house building worker is linked to £171,760 of construction expenditure. Therefore, it is possible to estimate the additional workforce associated with these expenditures. The additional expenditure converts into extra annual employment figures of between 83,465 and 98,667 construction workers depending on the sector delivering the new-build.

These additional construction workers represent between about 5 percent and 4 percent of the current workforce of 2,149,000, which would imply additional recruitment and training. Given that the sector lost more than these figures from the 2007 peak this should be achievable, but it might be difficult on top of the cyclic expansion and the requirements of the LCT.

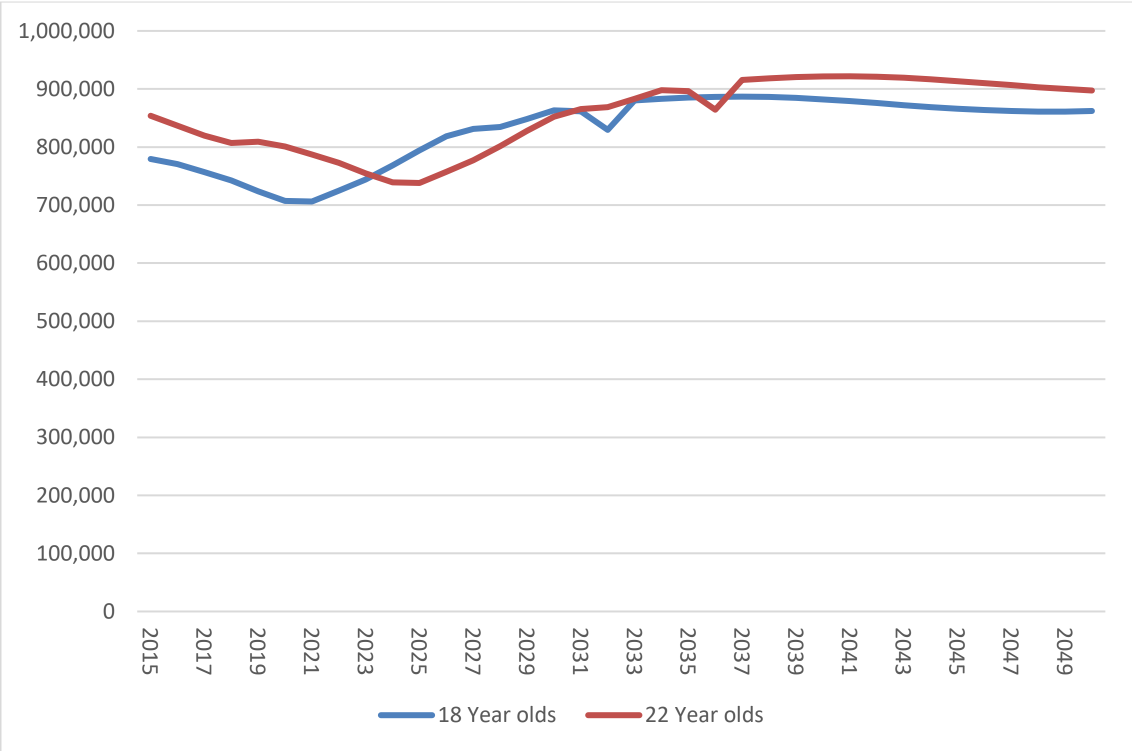
6.2.2 Demographic driven supply

The main driver of supply of new entrants to the labour market is the number of school leavers. Therefore, an examination of the likely supply of new entrants to the construction industry can be based on demographic forecasts. This was undertaken using Eurostat population projections.

Everything being equal, a greater number of young people will mean a greater number of labour market entrants and a greater number obtaining qualifications. An analysis of the Eurostat data shows that the number of UK 18 year olds and 22 year olds forecast to decline until 2021 and 2025 respectively, then increase again until 2023 and 2027 before declining slowly to 2050 and beyond, as shown in Figure 6.1. Overall, the demographic forecasts suggest that there will only be at maximum 14 percent more 18 year olds in 2036 than there were in 2015 and 8 percent more 22 year olds in 2040 than in 2015.

Although the changing demographic profile of the UK population is not a policy issue, it does demand a policy response. This subsection aims to examine the potential impact of the documented relative decline in the number of 18-year-olds entering the labour market over the coming 50 years (Dixon, 2003). This decline could mean that to maintain the size of the construction sector, a growing proportion of the cohort will need to be persuaded to enter the construction sector. It is also likely to necessitate the retention of older workers (Marley, 2015). There is also some evidence that an ageing of the workforce will make the adoption of innovative technologies and techniques more difficult (Prskawetz et al., 2006; Frosch, 2011). This issue is particularly important for the LCT, which will involve the mass adoption of innovation. The effect of this could be shortages of construction recruits at just the time when the demands of the LCT are at their greatest.

Figure 6.1: Forecast Numbers of 18- and 22-Year-Olds, 2015 - 2050



Source: Eurostat Central Forecast with Migration

In addition to these demographic issues, a further source of problems for the construction sector is its dependence on intermediate level qualifications, as the forecasts of educational attainment in Table 6.4 show that this group will be squeezed, as more people obtain tertiary level qualifications. This again requires timely policy and institutional interventions to ensure the supply of necessary skills to achieve the LCT.

Table 6.2: Forecasts for UK Educational Attainment by Level, 2015 to 2040

	Primary	Secondary	Tertiary
2015	10.4	61.7	27.8
2020	8.6	62.4	28.9
2025	7.3	63.0	29.5
2030	6.3	62.8	30.8
2035	5.4	62.5	31.9
2040	4.7	61.8	33.4

Source: Barro and Lee 2015

6.2.3 Forecasting specific occupations

In order to better inform policy development, it is useful to have forecasts of detailed occupational breakdowns of the various adaptation scenarios. This subsection outlines the methods and results of the forecasts undertaken here over the period of the LCT

Background

Forecasting specific occupations is difficult and rarely undertaken (Bailey, 1991). Partly, this is because the Standard Occupational Classification (SOC) changes every ten years in order to be used by the censuses. This reflects a relatively rapid change in job-titles and job content as a result of technical and other changes. The classifications have a degree on continuity, if only to maintain a linkage to the international ISIC classification (ONS, 2010). However, long time series at the detailed occupational level are not available and this limits the scope for producing models and forecasts. This problem has led to the use of a consistent classification over time for surveys of construction occupations, but this approach is necessarily broad-brush (Drever and Doyle, 2012).

Method

The method adopted in previous chapters is to start from the overall numbers involved and then characterise the construction subsectors that are involved with the activity and then use the occupational profile for the subsectors as the basis for an occupational breakdown. The breakdown for the adaptation scenarios use the occupational profile of civil engineering contractors as the bulk of the adaptation measures involve civil engineering. The additional building was easier to assign as the occupational profile of domestic builders was used.

Results

It is easier to forecast occupations that are dependent on specific higher education qualifications, as the classifications used by HE are more stable over time than the SOC codes. The supply of civil engineers has previously been modelled on the basis of historic trends (Edwards et al., 2004). Since the supply of civil engineers has been shown in Chapter 5 to be key to the success of the LCT. Therefore, using first degree entry data from the Universities and Colleges Admission Service (UCAS) covering the period 1994 to 2000, they showed that trend was downwards in terms of entrants, contrasted with growing and stable employment prospects. However, Table 6.5 shows a longer time series from 1994-95 to 2014-15 using data on graduates. Of more interest is the numbers of first degree graduates, as all the higher degree graduates will have had to have obtained a first degree previously. The higher degree numbers are included as they indicate the production of higher levels of skills, but they are more likely to include overseas students who, on graduation, are not available to the UK labour market. Therefore, the analysis concentrates on first degree graduates.

Table 6.3: Civil Engineering and All Subjects Graduates, 1994-95 to 2014-15

	Civil Engineers		All Subjects		Civil Engineers as a percentage of All Subjects	
	First Degrees	Higher Degrees	First Degrees	Higher Degrees	First Degrees	Higher Degrees
1994-95	3,110	732	237,798	46,968	1.31	1.56
1995-96	3,281	985	251,248	56,252	1.31	1.75
1996-97	3,178	896	255,260	59,002	1.25	1.52
1997-98	3,312	933	258,753	64,968	1.28	1.44
1998-99	3,182	1,041	263,671	67,175	1.21	1.55
1999-00	2,770	1,010	265,270	71,910	1.04	1.40
2000-01	2,640	1,225	272,665	86,530	0.97	1.42
2001-02	2,480	1,325	274,440	90,370	0.90	1.47
2002-03	2,320	1,245	282,380	98,885	0.82	1.26
2003-04	2,310	1,440	292,090	117,010	0.79	1.23
2004-05	2,515	1,670	306,365	119,445	0.82	1.40
2005-06	2,445	1,690	315,985	125,075	0.77	1.35
2006-07	2,790	1,835	319,260	128,395	0.87	1.43
2007-08	3,180	1,925	334,890	135,570	0.95	1.42
2008-09	3,635	2,165	333,720	140,965	1.09	1.54
2009-10	3,880	2,515	350,860	158,135	1.11	1.59
2010-11	4,090	3,185	369,010	182,605	1.11	1.74
2011-12	4,215	3,365	390,985	194,275	1.08	1.73
2012-13	4,370	3,205	403,770	193,295	1.08	1.66
2013-14	4,595	3,170	421,850	188,665	1.09	1.68
2014-15	4,305	3,400	395,580	191,215	1.09	1.78

Source: HESA data

The table confirms the analysis of Edwards et al., (2004), but shows that from 2004 the number of graduates started to increase in absolute and relative terms. It is tempting to think that this is a result of the Roberts' Review (Roberts, 2002) which provided increased funding and support for the education of people in Science Technology Engineering and Mathematics (STEM) subjects. This was a significant policy intervention and the timing of the increase in graduates is consistent with an impact from the review. Another factor leading to more civil engineers could be the trend towards more vocational degree subjects in an era of higher fees (Symes and McIntyre, 2002). Either way, the reversal of the trend indicates that simple trend prediction is inappropriate for forecasting construction skills supply especially at the level of specific skills. Factors such as the attractiveness of construction as an employer (Sedighi and Loosemore, 2012), the view of women of the sector (Amaratunga et al., 2006) and the degree industry level planning (Agapiou et al., 1995b) amongst other factors influence the level of supply.

6.2.4 Qualifications with long training

Earlier concern has been expressed in Chapter 5 about occupations within the construction sector that require long training and experience periods, as the lags these create may mean that the normal labour market signals that encourage people to obtain qualifications in shortage occupations may not apply effectively. Unfortunately, there is no data on required training and experience periods which makes identifying these "at risk" occupations empirically. Although, the Migration Advisory Committee (Migration Advisory Committee, 2011) has collected extensive anecdotal evidence and this was used, in part, to identify the bottleneck occupations in Chapter 5. However, Ofqual (the independent qualifications regulator for England) produces a database of regulated and approved qualifications. This database includes the minimum and maximum 'Guided Learning Hours' or teaching time required for the qualification. Guided learning hours can only be a proxy for the length of training and does not attempt to measure the amount of experience that is needed. However, this is the only available proxy for training and experience. An extract of this data was created, covering construction and engineering construction qualifications and is shown below.

Table 6.4 Minimum and Maximum Construction Teaching by Level of Qualification

Level	Measure	Minimum Guided Learning Hours	Maximum Guided Learning Hours
Level 0 to 2	N	218	218
	Median	114.5	118.5
Level 3	N	498	498
	Median	155.5	225.0
Level 4	N	372	372
	Median	314.0	360.0
Level 5 to 7	N	82	82
	Median	257.0	274.0
Total	N	1170	1170
	Median	180.0	230.0

Source: Analysis of Ofqual Registered Qualifications Database

Perhaps as expected, Table 6.6 shows that for higher level qualifications the minimum and maximum training periods were longer. The exception to this is the relatively small number of Level 5 to Level 7 qualifications which are designed to be at graduate and above level, where the training periods were on average smaller than for Level 4 qualifications, which are at an equivalent level to A Levels. Importantly, for each category the maximum guided learning hours are close to the minimums, it is only at Level 3 and below where previous experience or qualifications allow shorter training. Overall, this suggests minimum and maximum learning hours are a relatively good measure of the length of time required to obtain the qualifications.

Annex D contains a listing of the top five percent of qualifications from Level 3 and Level 4 with the names of the qualifications, the body responsible for the qualification and the maximum and minimum number of contact hours. This shows that most of the Level 4 qualifications with long training periods relate to gas installations and maintenance reflecting the demands of Gas Safe licensing (Gas Safe Register, 2011). Here the legal licensing requirements that mean that trained gas installers cannot be undercut by un-skilled competitors protects the investment in training and encourages people to acquire the skills. However, the analysis reveals a large number of other occupations that are not protected by licensing which also have long periods of training. These include qualifications aimed at those maintaining construction equipment and machinery, those producing formwork and reinforcement for concrete, as well as a range of specialist occupations such as steeplejacks and lightning conductor installers. These longer to obtain qualifications are potentially an indicator of occupations that could become bottleneck occupations. Importantly, there are many qualifications aimed at occupations already identified as potential bottleneck occupations using other measures.

6.3 Policy-driven additional demand

This section aims to analyse both the numeric and qualitative impact of a range of policy decisions. As previously stated, future policy decisions are difficult to predict, so this section cannot be fully comprehensive. However, as outlined above, there are three main policies that are relevant to the LCT which are currently under discussion by the Government. These policies are:

- Adaption to Climate Change
- Additional new build houses
- Counter-Cyclical Pattern of Investment.

In practice, many other policy interventions are likely to occur in response to economic and climate change issues other than those selected. However, the impacts in terms of cost of the three potential policy interventions are known and scalable, with the potential upper limit of their impact calculable. This will enable some quantitative analysis to provide some comparable foresight into each policy's potential impact in terms of UK construction skills demand and indicate whether this will become problematical.

The three policies are dealt with in turn below.

6.3.1 Adaptation to climate change

In addition to the future need to achieve the LCT by reducing carbon emissions to near zero (in line with the 2015 Paris Agreement) there will also be a need to respond to the negative impacts of climate change that are already locked-in as a result of current and historic emissions (Eriksen et al., 2011). In the UK, these impacts will mainly be summer overheating and water shortages, as well as sea, river and surface water flooding, which will result as sea-levels rise and rainfall increases (Committee on Climate Change, 2010). Each of these threats will require new policy responses or the expansion of existing policies. It is likely that summer overheating will be partly addressed by improved insulation of properties and measures linked to existing patterns of repair and maintenance. The major adaptation measures involving additional expenditure will most likely be a result of responding to flooding (Adaptation Sub-

Committee, 2014). This subsection, analyses adaptation, looking at estimates of the amount of additional construction work associated with responding to the threat of flooding and converts this into forecasts of the additional construction labour required.

There are many assessments of the costs of climate change, including the costs of flooding (Arnell et al., 2015; Sayers et al., 2015). However, there are fewer assessments of the costs of adaptation (Narain et al., 2011), and most of the available literature relates to the costs of adaptation in developing countries rather than western countries (Fankhauser and Burton, 2011). Recent work by HM Government has sought to model the impact of flooding and storm surges and ways in which to maximise resilience (HM Government, 2016). To date, the Foresight Future Flooding Project has produced the most detailed estimates for England and Wales of the future capital and operational costs of addressing the flood management issues caused by increased rainfall and rising sea levels (Foresight, 2004). The foresight review used four scenarios to show the range of costs and expenditures associated with flooding in England and Wales, as shown in Table 6.5.

Table 6.5: Estimated Required Annual Flood management capital costs England & Wales (£m/year) by scenario

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Fluvial and Coastal	75,600	77,200	22,100	22,400
Intra-urban	3,680	2,660	250	1,150
Risk reduction	2,140	1,860	900	610
Total costs	81,420	81,720	23,250	24,160

Source: Evans et al., 2008 p. 48 based on Foresight (2004)

The World Markets and National Enterprise scenarios assumed little efforts to reduce carbon emissions, so the sea level rise and storms consequences of climate change and the associated flooding risk are extreme. The Local Stewardship and Global Sustainability scenarios assume reductions in carbon emissions along the lines of those currently planned by UK policy. However, recent research suggests that the detrimental impacts of climate change, even if emissions are eliminated, will be more severe than expected at the time of the 2004 Foresight study. Forecast sea level rises, already built in by current emissions levels, are higher (Hansen et al, 2015) and storm surges are also higher (Vousdoukas et al., 2016), although in places natural processes may protect the coast, reducing the need for costly barriers (Lentz et al., 2016). Either way, when evaluating these scenarios, the costs of adaptation may be greater than assumed in the lower cost scenarios but less than those assumed for the higher cost scenarios.

Based on analysis by the Committee on Climate Change of funding for the Environment Agency's flood prevention measures, there was £643m expenditure in 2014, of which £344m was capital spending (Adaptation Sub-committee, 2014). This expenditure is significantly below the Environment Agency's Long-Term Investment Strategy (LTIS) Scenario 5 target of £879m which aims to reduce households at risk (Environment Agency, 2014). The 2014 spending is also significantly below the Foresight targets shown in Table 6.1.

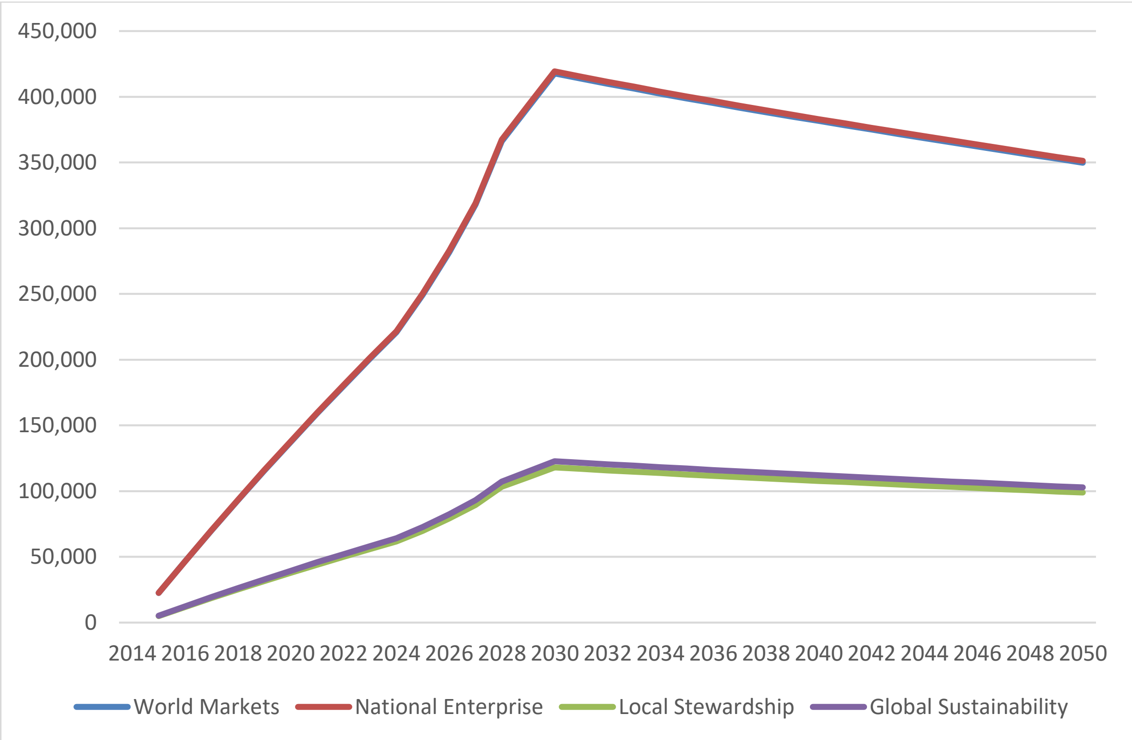
The most comprehensive forecast of UK capital expenditure for adaptation to address flooding from increased rain fall and rising sea levels is the Foresight 2004 study. This is now used to provide an employment forecast for the construction sector in order to implement adaptation measures.

Forecast

The forecast assumes that capital spending on flood defences rises over the next fifteen years to the Foresight levels from the £344m today, and uses the conversion factor of one civil engineering construction worker for every £162,800 capital spending on infrastructure. This is the conversion factor derived in Chapter 5. These assumptions suggest, at maximum, nearly 400,000 extra construction workers will be required. However, if additional adaption is required, due to higher than expected sea-level rises and higher than expected rainfall, then the required additional workforce could be more. In order to account for productivity increases the forecast assumes that construction productivity increases in line with the whole economy productivity increases generated in Chapter 4. These productivity increases are used because the historic data on construction sector productivity are very suspect (Abdel-Wahab et al., 2006).

Figure 6.1 provides a forecast of adaptation-linked construction employment. This forecast is based on a fifteen-year build up to the levels of adaptation expenditure from the Foresight report and a growth in adaptation productivity in line with the forecast levels of productivity growth from Chapter 4. Figure 6.1 shows that, in terms of employment, the World Markets and National Enterprise scenarios are almost identical with a peak of about 417,000 and 419,000 workers respectively. By comparison, the Local Stewardship and Global Sustainability scenarios, again almost identical in employment terms, peak at about between 118,000 and 122,000 additional workers respectively.

Figure 6.2: Forecast Construction Employment by Adaptation Scenarios



Source: Own Analysis

The extra 118,000 construction jobs due to the more optimistic adaptation strategy is probably an under-estimate, as the costs are for just England and Wales rather than the whole of the UK. The 118,000 jobs represent about a 5.6 percent increase on current construction employment of 2.1 million jobs, while the higher figure of 419,000 extra jobs represents about a 20 percent increase which might be difficult to achieve. However, the higher figures assume no effective carbon reductions and therefore hopefully will not apply. The employment and subsequent occupational forecasts are based on the assumption that these adaptation measures are largely civil engineering projects undertaken by civil engineering contractors. Indeed, the Foresight report identified shortages of civil engineers as a potential risk to implementing the required adaptation measures.

Moreover, it is possible that alternative approaches to flood adaptation might be considered, given the possible problems in funding and staffing the adaptation measures. These alternatives would involve using natural processes to mitigate the impact of high rainfall and storm conditions, since these are probably cheaper and involve less construction labour (Iacob et al., 2014; Rewilding Britain, 2016). However, there is still a need for further research to establish the effectiveness of the alternatives (Barlow et al., 2014). At the same time, it appears that sea level rises will be greater than anticipated requiring more coastal defences (Clark et al., 2016). Although, it is also recognised that natural processes might to an extent mitigate the impacts of sea levels rises (Kirwan et al., 2009; Lentz et al., 2016). Overall, the lower figures for employment impacts are the most plausible and it is possible that there will need to be less hard defences produced by civil engineering. The details of adaptation require further research to understand the employment and occupational impacts.

6.3.2 Occupational structure in 2050 by scenario

There are few details of the type of works intended to be undertaken as part of each of the adaptation scenarios. This, in turn, means it is difficult to accurately predict the occupational profile of those who would be employed in 2050 in each of the scenarios. However, on the assumption that the majority of the adaptation works involve civil engineering it is possible to produce a profile. As would be expected, the adaptation scenarios require a large number of civil engineers, which could be a problem given the large numbers of civil engineers already required for the DECC pathways. In addition to the higher levels skills required by the civil engineers, the adaptation scenarios are also dependent on relatively large numbers of construction machine operatives. These machine operatives, despite being considered largely unskilled, actually require more training than most unskilled workers in the sector

A breakdown by occupation of the additional construction skills demand for each of the possible scenarios proposed to achieve climate change adaptation is shown in Table 6.2. Details of the method used is contained in subsection 6.3.2.

Table 6.2: Occupations of Additional Construction Workers in 2050 by Scenario

2050	Adaptation National Enterprise	Adaptation Global Sustain-ability	Additional New Build
Production managers in manufacturing	7,700	2,300	**
Production managers in construction	24,300	7,100	7,100
Other Managers and Directors	17,600	5,100	3,600
Civil Engineers	34,000	10,000	**
Quantity Surveyors	7,700	**	**
Construction Project Managers	8,500	**	**
Other Professional Occupations	48,800	18,900	5,800
Associate Professional & Technical Occupations	40,700	11,900	4,800
Bookkeepers and Payroll Managers	**	**	**
Other Administrative Occupations	**	**	**
Personal Assistants	4,500	**	**
Other Admin, Secretarial Caring and Sales	30,000	8,800	6,900
Welding Trades	**	**	**
Pipefitters	**	**	**
Metal working production and maintenance fitters	4,400	**	**
Air Conditioning and Refrigeration	**	**	**
Electricians and Electrical Fitters	9,700	**	**
Telecommunication Engineers	**	**	**
Electrical and Electronic Trade n.e.c.	**	**	**
Steel Erectors	**	**	**
Bricklayers and Masons	**	**	**
Roofers, roof tilers and slaters	**	**	**
Plumbers and Heating and Ventilation	**	**	**
Carpenters and Joiners	7,300	**	12,700
Glaziers, window fabricators and fitters	**	**	**
Construction and Building Trades n.e.c.	7,800	**	14,100
Plasterers	**	**	**
Floorers and wall tilers	**	**	**
Painters and decorators	**	**	6,100
Construction and Building Supervisors'	15,100	4,400	**
Other Skilled Trades Occupations	45,800	17,600	21,100
Scaffolders and Stagers	**	**	**
Mobile Machine Drivers	11,600	**	**
Other Process Plant and Operatives	11,200	**	**
Elementary Construction Operatives	15,500	4,500	7,300
Other Elementary and Unskilled Occupations	18,600	12,100	5,729
Total	351,000	103,000	95,000

Source: Own Analysis

This table shows that adaptation measures are dependent on civil engineers and other professionals as well as numerous low skilled operatives. This reflects the occupational profile of civil engineering contractors which is used as the basis for this analysis. The additional housing option has a broader profile with a greater demand for skilled trades, reflecting the profile of house building contractors used in the analysis.

6.4 Confronting supply with demand

Forecasting demand is only useful if supply is also forecast and the two are compared. There are potential problems when forecast demand is greater than forecast supply. Therefore, such and analysis was conducted below by comparing the forecast numbers of construction workers for the DECC pathways from Chapter 5, economic growth from Chapter 5 and climate adaptation from earlier in this chapter with the demographic based forecast of supply from subsection 6.2.2

Method

To start it is necessary to summarise demand. This subsection draws together the forecasts form the previous chapters and produces a maximum and minimum forecast demand. In order to provide comparisons with population growth and past periods of construction growth these forecasts are then converted into annual growth rates.

The maximum annual rate of construction employment growth between 1994 and 2016 was eight percent between the July to September quarters of 2002 and 2003. The preceding quarter's annual growth rate was 6.6 percent and the following quarter's rate was 5.7 percent. This historic growth rate is taken as the maximum rate the sector can grow at without sustained policy interventions. Overall, during the 1994 to 2016 period the construction employment grew at an average compound growth rate of 0.821 percent. Since this growth rate was achieved when the numbers of 20 to 24 year olds were increasing at a compound rate of 0.207% the sector was taking a growing proportion of the entrants to the workforce.

The ability of the sector to continue to pull in a growing proportion of the upcoming cohorts when the growth is plateauing is central to the debate about future supply. Assuming that the 2050 construction workforce is composed of the underlying growth plus the additional workers required for the Friends of the Earth pathway and the lower Global Sustainability adaptation scenario as well as those needed to build sufficient housing. Table 6.7 shows that this additional construction workforce consists of about three quarters of a million taking the total 2050 numbers to just under three million.

Table 6.7: Forecast Demand for UK Construction Workers in 2050

	Total 2050 numbers	Growth from 2015 Baseline	Percentage Growth	Average Annual Growth Rate
Baseline	2,334,000	205,000	8.8	0.27
Baseline plus Friends of the Earth	2,706,000	577,000	21.3	0.71
Baseline plus DECC High Nuclear	2,635,000	506,000	19.2	0.63
Baseline plus National Grid	2,632,000	503,000	19.1	0.63
Baseline plus DECC MARKAL	2,609,000	480,000	18.4	0.60
Baseline plus National Enterprise	2,685,000	556,000	20.7	0.68
Baseline plus Global Sustainability	2,437,000	308,000	12.6	0.40
Baseline plus Additional Housing	2,429,000	300,000	12.4	0.39
Baseline plus FoE & National Enterprise	3,057,000	928,000	30.4	1.07
Baseline plus FoE & Global Sustainability	2,809,000	680,000	24.2	0.82
Baseline plus MARKAL & National Enterprise	2,960,000	831,000	28.1	0.97
Baseline plus MARKAL & Global Sustainability	2,712,000	583,000	21.5	0.71
Baseline plus FoE, Additional Housing & National Enterprise	3,152,000	1,023,000	32.5	1.16
Baseline plus FoE, Additional Housing & Global Sustainability	2,904,000	775,000	26.7	0.92
Baseline MARKAL, Additional Housing & National Enterprise	3,055,000	926,000	30.3	1.07
Baseline MARKAL, Additional Housing & Global Sustainability	2,807,000	678,000	24.2	0.82
Working Age Population	43,171,472	3,212,332	7.4	0.23
18 Year Olds	862,011	84,626	9.8	0.30
22 Year Olds	897,237	43,538	4.9	0.15

Source: Chapters 4, 5 and 6

Analysis

Overall demand comes from a combination of underlying demand, technical change, adaptation and other policy driven demands. Table 6.7 presents a range of such combinations.

Not all possible combinations are shown as the number of possibilities is too large for a table, however those that are included are considered the most informative and most plausible.

All of the combinations include the impact of underlying growth as a baseline, as shown in the first row of the table. This shows the predicted rate of growth in underlying construction is slightly higher than the rate of growth in the working age population as shown at the bottom of the table. As this suggests a stable proportion of the population within construction this should not pose problems in terms of recruitment and retention. Underlying construction employment growth could be much higher than predicted in Chapter 4 if higher rates of GDP growth are assumed. This would mean that underlying baseline employment growth would be much higher than the forecast growth in the working age population and the growth in 22 year olds. Both of which would suggest some problems ensuring that the baseline employment growth could be met.

The next group of combinations are ‘baseline plus’ and simply show the relative impact of each of the measures. These all are shown to be between twice or three times the growth rate in the working population. These growth rates should be achievable as similar growth rates have been achieved in the past, in particular during expansions following recessions. This also shows that the employment impact of the lower adaptation scenario and the additional housing are smaller than the LCT pathways, but smaller than the larger adaptation scenario which is comparable to the LCT pathways.

It is the employment consequences of the combination of the baseline growth, a technical change pathway and an adaptation scenario or additional housing that cause the real concerns. Unfortunately, there is a lot of uncertainty over the size of the adaptation required. Even if the LCT is successful and reverses carbon dioxide levels climate change already underway will lead to worse weather and rising sea levels requiring some form of adaptation. Therefore, these forecast larger demands on the construction sector, which combine the baseline with various

LCT pathways, as well as adaptation scenarios and potential additional housing, are possible. These additional demands may be difficult for the construction sector to meet.

The level of occupational supply is more difficult to forecast. The usual method used in occupational forecasting is to use demographic trends as the standard assumption is that without interventions the same proportions of each cohort would enter the occupation (Borghans et al., 1996). Table 6.7, therefore, includes the percentage growth and annual growth rates for the working age population, the 18-year-old cohort and the 22-year-old cohort. The working age population provides measure of the overall potential construction workforce, while the 18-year-old cohort is a proxy for apprentice entrants and the 22-year-old cohort for graduate entrants.

It is possible that some of the additional LCT generated construction labour demand may in practice be undertaken as part of the underlying construction activity. This would reduce the impact of meeting the demands of the LCT, but would reduce levels of new build. However, the DECC models assume that all new building is low- or zero-carbon and as such the underlying construction activity is as essential to achieving the LCT as the new electricity generation capacity included in the DECC pathways.

It is also possible that much of the installation of low-carbon infrastructure could be undertaken by overseas construction workers reducing the demand for UK based construction workers. However, similar activities will be underway in other countries meaning that they would have little surplus construction labour available to work in the UK and overseas might be an attractive place for UK based workers. As such it is safer to assume that there will be a no net movement in or out of the country of construction workers.

However, first the impact of the business cycle is examined as addressing the problems posed by the cyclic declines will be critical and it is the impact of the business cycle that is examined in the next section.

6.5 The impact of the business cycle

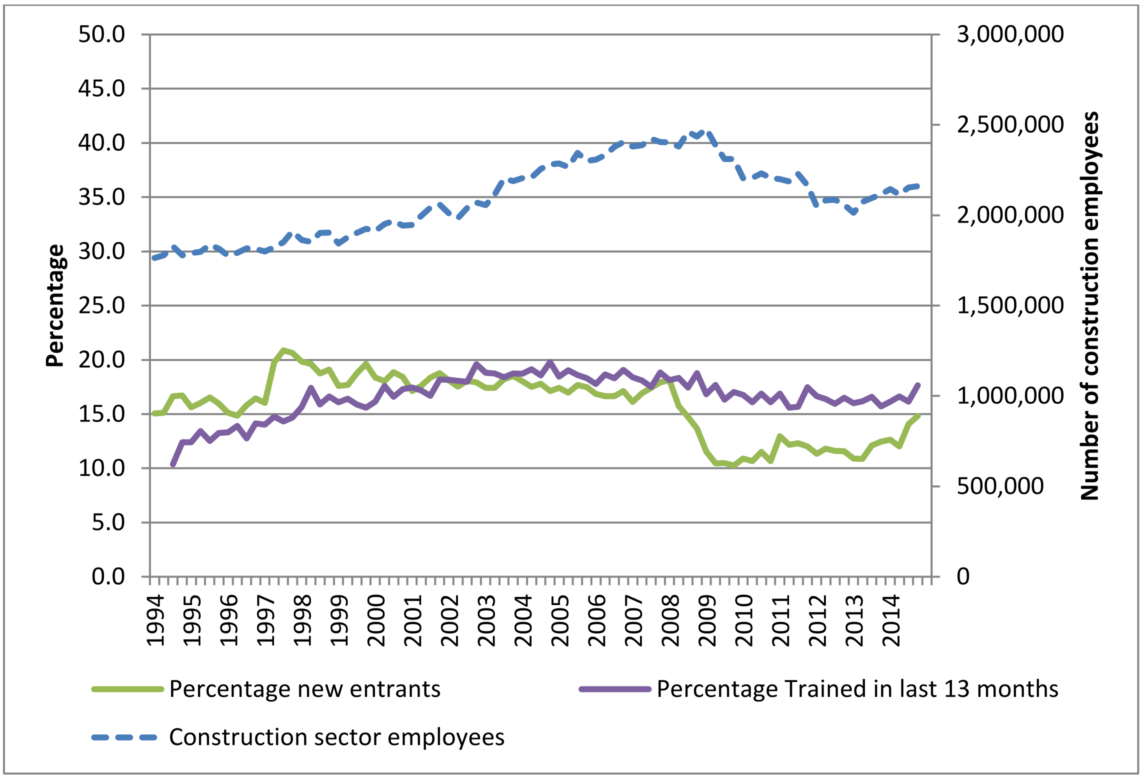
As previously discussed in Chapter 2, The impact of the business cycle remains the dominant feature for the construction sector influencing its structure, its pattern of recruitment and training and its ability to innovate.

6.5.1 Business cycle and construction training

This subsection aims to analyse the impact of the business cycle on the training requirements of the construction sector. The chief problem here is that many of those who have to leave the construction sector during recessions do not return to the sector once the upturn comes around (Agapiou et al., 1995b). This is a commonly asserted view of construction sector careers, but there are very few data sources that allow careers to be tracked, so the main evidence is the age profile of entrants, which does not reflect the re-hiring of people who have been laid off during recessions. This, in turn, means that their training effectively goes to waste and additional training programmes are required to build up the workforce from scratch. Admittedly, there are usually efforts to retain the most skilled workers by employers. Also, many skilled workers in construction move to self-employment, and reduced working hours, during recessions. However, the potential scale of this problem and the impact on future training requirements has not been fully analysed before. Therefore, this subsection represents the first attempt to quantify the issue and uses the core economic forecast of Chapter 4 to predict the future consequences of the business cycle on construction demand.

Figure 6.3 shows the relationship between training, construction sector employment, new entrants to the sector and the business cycle. This figure uses quarterly Labour Force Survey (LFS) data. Importantly, the training indicator just reflects incidents of training and nothing about its intensity or purpose. The ‘new entrants’ data is based on the numbers who were not employed in the construction sector 12 months before the survey date.

Figure 6.3: Training, new entrants and construction employment



Source: Own analysis of Labour Force Survey

This chart indicates that as new entrants grew during 1994 to 2000 the incidence of training also grew. From 2001 to 2008, as the number of new entrants stabilised at about 18 per cent of the workforce so did the incidence of training. However, from 2008 to 2011, when the proportion of new construction entrants is shown to drop dramatically, as might be expected during recessions, there is also a fall, but less dramatic, in the incidence of training.

Analysis of the recession that started in 2008 provides the basis for understanding the dynamics and consequences of recessions on the demand for training. Using the quarterly Labour Force Survey (LFS), it is possible to examine the average age, qualification level, length of service, whether or not individuals received training in the previous three months and other labour market variables. Using the same quarterly structure, it is possible to link this data to the numbers of construction apprentices and the level and type of construction activity. Table 6.3

provides a range of these indicators in an attempt to further understand the business cycle dynamics of training.

Table 6.8: Key Construction Workforce Indicators Over the Business Cycle

April to June Quarter	% receiving training in last 13 weeks	% with NVQ Level 4 plus qualification	% recruited by current employer in last 6 months	% self-employed	% working for small firms	Size of the construction workforce (2007 = 100)
1995	13.4	11.1	16.0	44.9	28.2	75.3
1996	13.9	12.2	14.9	45.7	28.1	75.0
1997	14.8	11.8	19.7	38.6	33.1	76.3
1998	17.4	12.0	19.6	35.6	35.2	77.6
1999	16.4	11.7	17.7	35.9	35.6	78.7
2000	17.6	13.0	18.0	33.1	36.7	81.7
2001	17.2	13.3	17.6	33.5	35.4	83.6
2002	18.1	12.4	17.5	35.6	35.1	83.1
2003	18.7	13.0	17.4	36.9	34.7	88.6
2004	19.1	13.9	17.5	37.4	35.0	92.5
2005	19.0	14.1	17.0	37.2	34.0	94.9
2006	18.7	14.9	16.6	35.7	34.4	97.7
2007	18.1	14.8	16.9	37.9	34.1	100.0
2008	18.3	14.6	15.7	37.0	34.8	99.6
2009	17.7	18.9	10.5	34.2	34.8	100.0
2010	16.1	18.8	10.7	37.0	32.7	92.4
2011	15.6	20.6	12.2	36.6	33.9	91.6
2012	16.4	19.1	11.8	39.7	31.7	87.2
2013	16.2	22.6	10.9	39.0	31.1	86.8
2014	16.6	22.1	12.0	40.2	31.1	88.6
2015	16.8	21.4	13.9	39.4	32.2	88.0

Source: Own analysis of Labour Force Survey

The table shows that the proportion of the construction workforce recently recruited falls in the years following the onset of the 2007 recession and the average age increases and then stabilises. Reflecting this, the number of apprentices virtually halves between 2007 and 2011 and barely increases in 2013 and 2015. This suggests that the initial impact of the 2007 recession is the slowing of recruitment of young entrants which, as a consequence, leads to an increase in average age of the workforce. Interestingly, as the recession continues, the proportion with NVQ Level 4 and above qualifications increases. The data on average age, which is not presented in the table, but shows a remarkably stable average age through the recession which suggests that the sector continues to differentially lose the older and less qualified. However, this does still mean that the sector loses experienced workers during recessions, even if they are not the most qualified.

The pattern of self-employment and employment by smaller firms is also interesting. There was initial stability during the recession of self-employment, followed by a growth from 2009 to levels higher than before the recession. In terms of small firms, there is a steady decline in the numbers working for firms with fewer than 25 employees. A possible reason for this pattern is that there has been a fragmentation of the workforce, in response to the downturn in the business cycle, with small firms breaking up and the more qualified becoming self-employed. However, much of this self-employment may be false and encouraged by advantageous construction sector specific tax procedures (Behling and Harvey, 2015).

Regardless of the real status of these self-employed construction workers, it has been argued that they are less likely to train or be trained (Forde et al. 2008). Table 6.9 presents on data on self-employment and training from the October-December 2015 LFS for the UK. The table shows that self-employed construction workers are far less likely to have received training in the last 13 weeks (8.6% compared to 23.7% for employees).

Table 6.9: Construction Sector Self-Employment and Training

	Not trained in last 13 weeks		Trained in last 13 weeks		Total	
	(Number)	(%)	(Number)	(%)	(Number)	(%)
Not Self-Employed	882,110	68.5	305,633	23.7	1,287,743	100.0
Self-Employed	808,566	91.4	76,135	8.6	884,701	100.0
Total	1,790,676	82.4	381,768	17.6	2,172,444	100.0

Source: Own Analysis of the LFS

This is of significance given the importance of innovation for the LCT and the linkage between innovation and training to provide the new skills needed.

Table 6.10 examines the available data on the number of construction apprenticeships starts and completions between 2002 and 2016. This is a period when Government policy has been to support apprenticeships and this is currently the main form of vocational training available. The table shows that apprenticeship starts within the construction sector began from a low base and grew to a peak in the academic year 2008/09 and then collapsed with the recession, with a lowest level in 2012/13. In comparison, the data for 'all apprentices' continued to grow through the recession. This again is significant as it shows the impact of the business cycle particularly on construction and has policy and training implications.

Table 6.10: Construction Apprentices and the Business Cycle

	Number of construction apprenticeship starts	Number of construction apprenticeship completions	Number of all apprenticeship completions
2002/03	15,860	2,440	42,400
2003/04	20,810	3,600	49,300
2004/05	25,000	6,900	67,200
2005/06	21,090	12,070	98,700
2006/07	27,300	16,160	111,800
2007/08	27,200	17,080	112,600
2008/09	23,440	18,980	143,400
2009/10	20,550	16,890	171,500
2010/11	22,420	14,240	200,300
2011/12	13,920	12,600	258,400
2012/13	13,730	9,060	252,900
2013/14	15,890	8,030	255,800
2014/15	18,290	8,470	260,900
2015/16*	15,070		

Source: BIS FE Data Library: Apprentices

6.5.2 Counter-cyclical pattern of investment

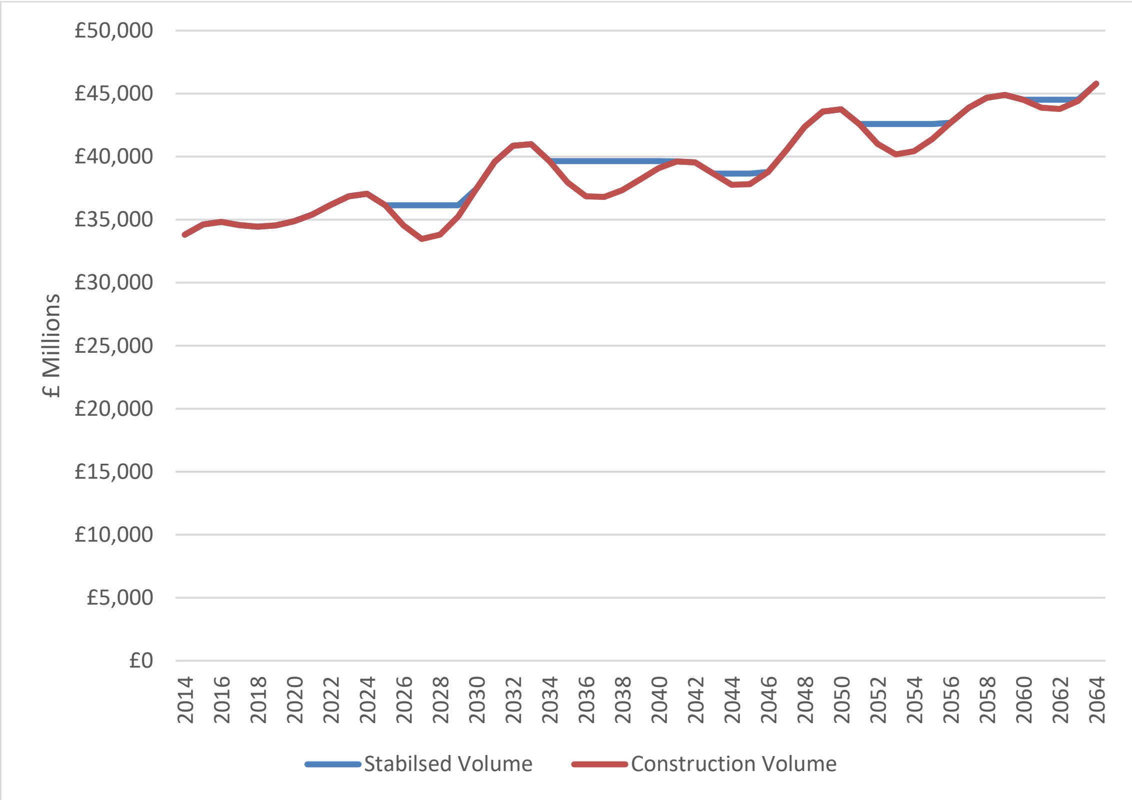
A classic Keynesian response to business cycle downturns is to increase government expenditure on infrastructure. By increasing spending against the cyclical trend, i.e. counter-cyclical spending, this investment minimises the impact on the economy of downturns.

Importantly for the construction sector, any counter-cyclical spending maintaining construction activity minimises the loss of skilled labour during the downturns. Section 6.5 explores the details of the impact of the business cycle on UK construction skills. However, in brief, downturns trigger a collapse in the recruitment of young workers, a halt to apprenticeship training and a loss of older experienced workers from the sector.

This subsection analyses the potential size of government interventions and the impact on the construction workforce and the levels of training needed to replace those lost to the industry during recessions. Figure 6.2 shows a hypothetical pattern of intervention, as a result of the forecast business cycle from Chapter 4. It also assumes a political willingness to make this sort of intervention, which currently is not certain. The interventions assume that additional infrastructure investments would only start once a recession has started and would be designed to stabilise construction activity as well as the existing workforce. The trigger would be a quarter with declining GDP, which is the standard definition of a recession, leading to the start of investment. The investment would have the objective of maintaining the level of construction activity and construction employment at that quarter's level.

Using these assumptions, and the forecast business cycles from Chapter 4, Figure 6.4 shows the impact of these interventions. The analysis suggests investments of £7.7 billion between 2026 and 2029, £11.7 billion between 2035 and 2040, £1.7 billion in 2045 £7.3 billion between 2052 and 2055 and, £1.4 billion in 2063. These are large sums of money but are comparable with sums involved in the adaption to higher rainfall and higher sea-levels outlined in subsection 6.3.1. By sustaining the construction workforce during recessions, this sort of additional investment could help to sustain the needed expansion in the construction workforce. Additionally, this would involve bringing forward the infrastructure expenditure that is needed to achieve the LCT and adaptation. Therefore, the investment will in practice also reduce the peak levels of LCT and adaptation construction activity making adaptation more possible. As this is about maintaining construction employment this expenditure cannot be considered to be creating additional employment.

Figure 6.4: Theoretical Impact of Construction Stabilisation



Source: Own Calculations

6.6 Lagging skills institutions

In a coevolving system, it would be the norm for institutions to evolve alongside the other components in the system, as the following quote examining skills institutions makes clear:

> *"Formal institutions do not survive long stretches of time by standing still. The language of stasis and inertia is particularly unhappy because as the world around institutions is changing their survival will not necessarily rest on the faithful reproduction of those institutions as originally constituted, but rather on their ongoing active adaptation to changes in the political and economic environment in which they are embedded."* (Thelen, 2004, p 293)

This means that the norm would be for the skills and the operation of skills institutions to develop in parallel with technical change and economic development. However, this is not always the case and there are many institutional and governance reasons why this might not be the case leadings to lags between the sub-systems of the coevolving system and the emergence of skills shortages. It is argued that lagging sub-systems cause disruption to the overall co-evolving system and in the case of these skills institutions skills shortages.

6.6.1 Employer-led institutions

The main guiding approach to the operation of skills institutions is to be 'employer-led' (Payne, 2008a). This means that skills institutions should primarily take their lead from employers and respond to their requirements.

The approach has been criticised from early on, with Peck and Jones (1995) providing a critique of Training and Enterprise Councils and their employer led motivation, although, sometimes it appears the concept of employer-led developments is more at the level of rhetoric as an analysis of the development of English diplomas for 14 to 19 year olds suggests (Ertl and Stasz, 2010). Politically driven targets and interventions have as much to do with the direction of developments as the employer-led guidance (Keep, 2006). In Scotland, in particular, there has been a growing realisation that the skills demanded by employers may not be appropriate and the way in which employers utilise skills and articulate their needs be addressed (Payne and Keep, 2011). This has led to the adoption, at least within Scotland (Anderson, 2010), of the idea of 'Skills Ecosystems' that first emerged in Australia (Hall and Lansbury, 2006). However, the employer engagement often determines funding of both the skills institutions and training schemes (Mazenod, 2014) which means that the role of employers is still dominant in the system.

The idea that dominance by one component or sub-system of a co-evolving system can cause imbalances has been applied to the relations between institutions and technical change within electrical networks (Finger et al., 2005; Künneke, 2008; Künneke et al., 2010). Finger et al. (2005) argue that the idea of the coevolution of institutions and technologies implies coordination between them and that this has implications for the functioning of both the institutions and technologies should that coordination break down. This idea built, in part, on earlier work by von Tunzelmann (2003) who argued that governance mechanisms and technologies coevolve with a 'network alignment' necessary for successful industrial revolutions. The extension of these concepts of the negative impacts of imbalances to the co-evolving relationships between growth, technology and skills allows a deeper understanding of their long-run dynamics, which is particularly pertinent to the LCT. An over emphasis on employers in determining the role of skills institutions is, therefore, potentially detrimental.

The German apprenticeship system, which was seen as one of the models for the UK's employer led system (Brown and Evans, 1994) has more recently come under criticism within Germany, due to poor results on international comparisons (Deissinger, 2004). Despite this the German system is usually considered to produce better results. In addition to the central role for employers there are additional reasons why the German apprenticeship system produces better results, these include a greater role for trade unions and better careers advice (Brown and Evans, 1994; Dieckhoff, 2008).

In the UK, the dominance of the employer-led philosophy, combined with constant Government interventions into funding mechanisms, qualifications, structures and institutions has led to criticisms of the system (Keep, 2006). These, in turn, have led to many proposals for reform of the vocational qualifications (Raffe, 2015), the institutions (Sainsbury, 2016) and funding mechanisms for apprenticeships with the introduction of a levy in England (DfE. 2016).

Gann and Senker (1998) argued that 21st century construction training in the UK would need to have a generic orientating foundation programme to address the needs of innovation and a changing industry. Although, Gann and Senker also provided evidence that the CITB had sought such an approach, it had been defeated by the employers' demands for qualifications covering very specific trades. However, eventually, the idea of a common foundation for UK construction training may result from the recent reforms to the apprenticeship system which have been proposed by the Sainsbury Review (Sainsbury, 2016) and the subsequent White Paper from the Department for Education (DfE, 2016). However, the current revisions to the apprenticeship system, which proposes the introduction of a more widespread levy, will do little to rebalance the fragmented governance systems of vocational training (Keep, 2015a).

The next two subsections provide mini examples to illustrate where an over emphasis on employer views has caused problems for the two main skills institutions covering the construction sector the CITB (Construction Industry Training Board) and the ECITB (Engineering Construction Industry Training Board). Subsection 6.5.2 evaluates the CITB Green Deal qualifications in relation to policy and the next 6.5.3, the ECITB Hinkley Point Apprentice initiative.

6.6.2 CITB green deal qualifications

The Construction Industry Training Board (CITB) is levy funded by the larger construction industry companies. The levy funds are then used to provide training for the sector. In practice, this means the CITB is tied to the interests and demands of the larger construction companies.

The Green Deal was a government scheme whereby the costs of energy efficiency measures were recovered via gas and electricity bills, with savings from the measures intended to be greater than the additions to the bills. In order to boost consumer confidence in the scheme a system of licensing (Sadler, 2008), whereby assessors and installers needed to have specific qualifications before they could work on the scheme was introduced. Some safety-critical construction occupations, specifically gas appliance installers and electricians had already been licensed. Additionally, other low-carbon occupations are licensed, including energy auditors and microgeneration certification scheme (MCS) installers (Jagger et al., 2014). However, the certification and licensing component of the Green Deal emerged relatively late in the policy development process. The CITB was then asked to develop qualifications for Green Deal installers that could be used as the basis for certification and licensing. The qualifications were to be based on a set of technical specifications developed by the Building Research Establishment (BRE) as a publicly accessible specification (PAS) 2030 (BSI, 2011). The process of qualification development was quicker than usual and the qualifications were in place for the launch of the Green Deal (Pye Tait Consulting, 2012). This success reflected the National Occupational Standards (NOS) for construction that were already in place. These are the building blocks of vocational qualifications for construction, covering the technical aspects of Green Deal installations. The main difficulty that the CITB had in developing the new qualifications was that they were intended to cover retrofits in occupied dwellings and they had no NOS covering this situation. Developing these NOS took all the time available and meant that it was difficult for providers to develop training ahead of the Green Deal launch. The CITB's levy funding comes from large contractors, working on new build on green or brown field sites, and not from the small contractors that typically undertake the repair and maintenance of occupied dwellings. This meant that their employers had no need for NOS covering working in occupied dwellings and the CITB had not previously developed them. (Personal Communication, 2013). This dependence on employers and their existing training requirements makes it difficult for the skills institutions to anticipate change and respond to innovation. As a result, qualification development often lags behind technical and other developments.

6.6.3 ECITB Hinkley Point apprentices

The Engineering Construction Industry Training Board (ECITB) is the other remaining levy funded training and qualification provider in the construction sector. They cover those building structures which have a large engineering component, such as off-shore oil and gas, power stations, chemical plants, large scale wind power and nuclear plant decommissioning. In 2012 the ECITB announced that the sector needed to recruit over 60,000 skilled workers over the next 10 years (ECITB, 2012a). The future demand for workers within the scope of the ECITB will be driven by building the engineering part of power stations, offshore wind turbines and replacing inefficient industrial plant. It is calculated that current work on nuclear new-build and nuclear decommissioning represents 21 per cent of the workforce within the ECITB scope (ECITB, 2016a). Although, Hinkley Point C nuclear new-build in Somerset by EDF and other nuclear new build will increase the numbers and proportions involved.

Hinkley Point C will require large numbers of high-integrity welders, amongst over skilled workers. Doosan Power Systems, who obtained the preferred bidder status for work on the station in 2015 (Doosan, 2015) had earlier received Government funding of £4m, matched by another £4m from the ECITB to train 790 welders for Hinkley Point and other nuclear work (Doosan, 2013). This investment was funded by the 'Employer Ownership of Skills Programme' required investment by the employer, in this case the money came from the ECITB's levy fund, which was then matched by the Government (UKCES, 2013). Doosan provides the bulk of those trained in the UK. However, despite the efforts of Doosan, the numbers being trained overall is still below the numbers of welders forecast to be required for nuclear new-build by the ECITB (ECITB, 2016b), Other employers, faced by uncertainty over nuclear new-build, have not been training welders and, at present, Doosan only trains the number of welders that they do because of the large scale of Government and ECITB subsidy. Doosan could anticipate sufficient work for welders, even if Hinkley Point did not go ahead so was willing to invest in their training. However, this confidence was not sufficiently widespread amongst employers and therefore the ECITB could not release more funds and the Government was also unwilling to invest. This inability to anticipate future demand, combined with the relatively long training period for welders holds back investment and probably will cause shortages in the future.

6.6.4 Lags and their consequences

There are a range of problems with the employer led system that lead to inertia and lags in the skill system and consequently to skills shortages. There are a variety of reasons for the inertia, and the above histories provide examples of some of these reasons. The main problem, as illustrated in the Hinkley Point example, is how construction employers respond to uncertainty by delaying decisions to train or recruit skills, hoping to employ specialist subcontractors potentially required in the future. This response to uncertainty has many characteristics of a more sophisticated ‘real options’ approach which calculates the value of deferring decisions, but in practice is based on simpler strategies adopted by construction employers (Ford et al., 2002).

Similarly, uncertainty in policy decisions impacts on institutions. It is more difficult for the skills institution to anticipate future demand, even if they have a role in forecasting future demand, as anticipation can be seen as potentially wasting money to deal with an outcome that might not occur. It is simpler to wait until the situation is clearer, even if this then could cause problems of late delivery of a response. This cautious response to uncertainty by employers is transmitted to the skills institutions and underlines one of the problems associated with an employer-led skills environment. Therefore, this highlights the for the Government to attempt to reduce uncertainty by having a clear plan for future LCT investments rather than leaving the transition to market forces.

Inertia by a sub-system of a coevolving system can be disruptive, the inertia can emerge as a result of too weak a linkage between elements (Inkpen and Beamish, 1997) or too strong a linkage (Burgelman, 2002). Skills shortages can emerge for a variety of reasons: necessary qualifications may not be developed in a timely manner; poor or absent careers advice might mean there are insufficient qualified applicants; employers may not feel willing to sponsor training in a critical area; or technical change might mean that the skills being taught are no longer applicable. The agility needed by skills institutions to respond to the complexity (Room, 2011) surrounding skills and their supplies may be hampered by funding concerns or inappropriate governance.

Historically, there has been evidence that UK skill shortages have depressed productivity growth and that there were strong sectoral differences (Haskel and Martin, 1993a). In this situation, Haskel and Martin argue that the skills institutions were not providing sufficient or appropriate skills. Equally, there is more recent evidence that UK training has not kept pace with the changing skills demand resulting from technical change, even with rising levels of training (Haskel and Martin, 2001). At the same time, evidence from the U.S. suggests that their training systems were undersupplying those with intermediate level skills (Kochan et al., 2012). This is at the same time as which high level skills were in high demand and being well rewarded in the US (Buera et al., 2015). There is similar evidence from the UK about under supply of intermediate skills and a demand for high level skills (Machin, 2001). Overall, research therefore suggests that skills shortages are part of a complex system driven by differing changing demands. These demands are partly driven by technical change as well as underlying growth of sectoral demand, matched by divergent patterns of supply and governance. Finally, where one sub-system lagged behind the others this causes imbalance and skills shortages.

Ensuring that there are sufficient numbers of construction workers is one thing, but it is more difficult to ensure that the skill mix required is in place. This is partly because messages about skill requirements are not clear and cause mismatches (Sala, 2011) and often local demand can respond to local skill mixes (Dustmann and Glitz, 2015). Equally, there is evidence that the skill-mix used by employers varies over the business cycle, as availability changes (Kelly and Lewis, 2010).

The assumption is that within a co-evolving system the skills-mix produced will meet the skill-mix demanded. Within coevolving systems, it is the norm for the sub-systems to develop in tandem (Nelson and Winter, 1982). It is well known that the mix of skills demanded by economies change as technology change, however there is also evidence that institutional and organisational change can drive the skill mix (Piva et al., 2005). This is especially the case within skills systems where employers or individuals pay for the training required. However, the same reasons that can cause skill shortages can also cause problems with the skill mix produced. The structure of the UK construction sector, with many small and micro companies, can magnify the problems communicating messages about future required skills mixes (Watson and Sharp, 2007).

6.7 Potential policies to increase construction employment

This section aims to examine a wide range of policies that could be employed to increase recruitment by the construction sector. This is not the place for a formal review of the construction skills training system, as has been undertaken in the past, for example by Gann and Senker, (1998). However, there are issues, other than the LCT, that are the direct consequence of policy decisions which could have an impact on either the demand for construction skills or their future supply. These issues all impact on the ability of the skills policy system to respond in a timely fashion to changes in underlying demand and impacts of technical changes on the construction skills necessary to achieve the LCT. Importantly, if these policy responses do not resonate with, or lag behind, the patterns of technical change, or underlying growth in the UK construction demand, there is potential for the creation of disruptive skills shortages (Jagger et al., 2013). Therefore, in order to allow the smooth progression of the LCT in the UK, policy responses need to address the following issues:

- Certainty, in particular over the choice of DECC pathway and technical options
- Support for STEM Subjects
- Attractiveness of construction
- Capacity to Train

- Impact of Licensing
- Limits to Migration.

These are discussed below.

6.7.1 Uncertainty

There is uncertainty over the technical components of the actual pathways adopted to achieve the LCT (Hughes et al., 2013). However, there is also considerable and, unfortunately, growing uncertainty as a result of recent LCT policy changes (House of Commons Energy and Climate Change Committee, 2016). This subsection aims to analyse the impact of this uncertainty. In particular, the subsection concentrates on the impacts of uncertainty on the construction sector's ability to deliver the LCT.

A recent House of Commons Energy and Climate Change Committee Report focused on the impact of uncertainty on low-carbon investments (Energy and Climate Change Committee, 2016). This report noted that abrupt policy changes reduced investor confidence, increased risk premiums and led to higher long-term energy costs. In their written evidence to the Committee, many of the energy companies noted that current policy uncertainty is also impacting skills investments[1], although this aspect was not noted in the Committee's report (Energy and Climate Change Committee, 2016).

There are a range of measures that can help ensure certainty. For the UK critical initiatives involve signing the 2015 Paris Agreement on Emissions Targets and for the Government to accept and act on the Committee on Climate Change recommendations (Committee on Climate Change, 2016). Since many low-carbon technologies utilise the same broad mix of skills the

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[1] http://www.publications.parliament.uk/pa/cm201516/cmselect/cmenergy/542/54213.htm

commitment could be skills rather than technologies. However, providing support for specific technologies sends a clearer message even if training support is for generic skills.

6.7.2 Support for STEM subjects

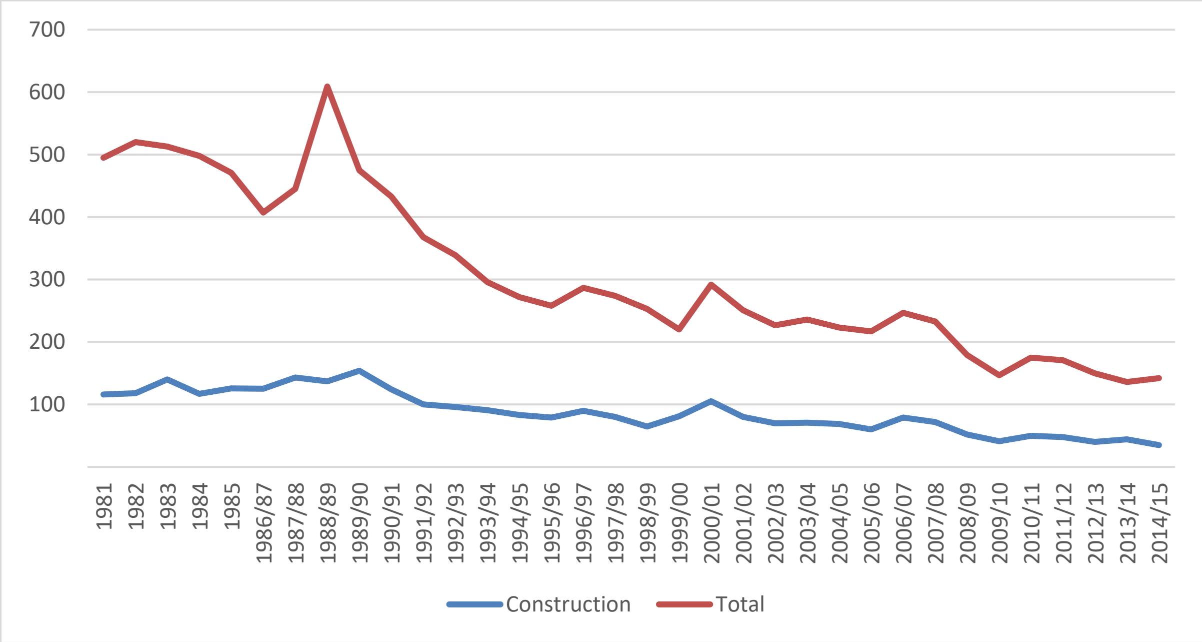
It has long been recognised that there is a synergy between supporting STEM subjects and supporting low-carbon skills (Aldersgate Group, 2010). Civil engineering is the clearest low-carbon beneficiary of support for STEM. However, lower level STEM skills are also essential for the construction industry, especially an innovating construction industry (Gluch et al., 2009). This means that support for STEM subjects needs to start at schools and maintain a clear vision of later careers depending on STEM (Roberts, 2002). Further efforts at schools to support STEM are therefore recommended to improve construction recruitment.

6.7.3 Attractiveness of construction

If the construction sector is to attract a greater proportion of the labour market, it needs to improve its attractiveness, especially for those groups which are currently under-represented within the sector (Build Up, 2012) Two groups that the construction sector needs to be more effective at recruiting, if it is to meet the higher levels of recruitment needed to achieve the low-carbon transition, are women and graduates, as previously discussed in Chapter 2.

A review of the status of women in the sector concluded that the: “image of the industry, career knowledge, culture and working environment, family commitments, male dominated training course and recruitment practices are the major barriers to women in construction.” (Amaratunga et al., 2006, p 568). The image of the industry and career knowledge are easier to address and many of the other barriers are likely to respond to increasing numbers of women in the sector. However, women are known to avoid sectors and occupations that are perceived to be dangerous (Grazier and Sloane, 2008; Heckman et al., 2009) and this works against female employment in the construction sector. This is despite falling numbers of fatal accidents in the sector as shown in Figure 6.5, albeit that the numbers are not falling as fast as in the rest of the economy. Further improvements to health and safety, and perceptions of the safety culture, within the construction sector could be critical for increased female recruitment.

Figure 6.5: Fatal Injuries for the Construction Sector and All Sectors, 1981 to 2014/15



Source: Analysis of HSE RIDDOR Data

There are arguments that female entrants could come as construction professionals whose working environment is considered safer and more female friendly (Construction Industry Council, 2009). Equally, others argue that green construction would be more attractive (Stevens, 2009). However, there is some evidence from the USA that green construction is more accident prone than standard construction (Rajendran et al., 2009; Iii et al., 2012; Dewlaney and Hallowell, 2012). The suggestion is that low-carbon construction being more innovative is less understood and hence more-risky and that with time it will become safer (Iii et al, 2012).

However, the negative impacts of perceived danger in construction by women could be offset by a higher than average salary. Indeed, salary increases are often used to meet increasing demand.

In fact, a commonly used measure of skill shortages is increases in earnings by occupations or sector relative to the norm.

These salary increases reflect an attempt to make the occupations or sectors more attractive. Table 6.10 provides a time series of weekly pay for construction workers and all employees. This shows that construction pay has been consistently higher than the average income across the economy. More importantly, the table also provides the ratio of construction earnings to the average across the economy. This ratio shows that during upswings in the economy, construction incomes rise faster than average incomes, reflecting skills shortages, and its attempts to make the sector more attractive. Indeed, the upswing of 2015 and early 2016 has led to Construction Industry Joint Council (CIJC) agreeing an increase in construction wages of 2.5 percent from 25th July 2016 and a further 2.75 percent from June 2017 (UCATT, 2016). These pay increases are greater than inflation and greater than the increases being offered elsewhere, making the sector increasingly attractive to new recruits.

Table 6.11: Median Weekly Pay All Employees and Construction, 1997 to 2015

	All Employees	Construction	Construction as a percentage of All
2015	£425.8	£529.6	124.4
2014	£417.9	£523.2	125.2
2013	£415.3	£519.4	125.1
2012	£405.8	£505.8	124.6
2011	£400.0	£504.0	126.0
2010	£403.8	£506.3	125.4
2009	£397.1	£498.6	125.6
2008	£388.8	£495.0	127.3
2007	£376.0	£476.6	126.8
2006	£363.0	£461.4	127.1
2005	£349.1	£443.0	126.9
2004	£345.5	£434.2	125.7
2003	£334.8	£415.0	124.0
2002	£324.8	£399.4	123.0
2001	£312.5	£383.9	122.8
2000	£299.6	£359.0	119.8
1999	£290.0	£344.6	118.8
1998	£280.2	£323.2	115.3
1997	£268.9	£310.4	115.4

Source: Analysis of ASHE data

Thus, by timely policy interventions to improve safety within th*e sector to improve its negativ*e appeal to women, alongside improved *remuneration*, should increase recruitment within construction to help meet the employment demands of the LCT.

6.7.4 Capacity to train

This subsection aims to explore the capacity of the UK education and training system to identify any expand training requirements necessary to meet the needs of the LCT. Currently, the Further Education system prioritises supporting apprenticeships and has little funding for training people outside of employment (Keep, 2015b). The collapse of construction apprenticeships (See Chapter 2 subsection 2.3.5) implies there may be a reduction in the ability to train the construction workers predicted to be required by the employment forecasts in Chapter 4 and 5.

Furthermore, in addition to considering the numbers that need to be trained, there is also a need to consider the number and skills of the required trainers and educators. Currently, the Construction Industry Training Board (CITB) has an On-Site Assessment and Training (OSAT) model. This involves training to meet any identified skill deficiencies. This is achieved on site, by the assessment of completed pieces of work and documentation in order to award qualifications (Pye Tait Consulting, 2011). These qualifications are then recorded on the CITB card which has a mandatory health and safety component. This model is advantageous as it is cheap to deliver and does not involve the learner leaving the workplace to attend a college. In addition to being cheap, the OSAT model, by reducing the time off work for training, is favoured by employers and Government. Given the employer led governance systems for training in the UK (Payne, 2008) it is easy to see why this approach is promoted.

However, this National Vocational Qualification (NVQ) based training and assessment system has been criticised as not providing sufficient underpinning knowledge (Grugulis, 2003). The OSAT model works well in a static technical climate, where knowledge can be passed on by peers. However, the model does not work so well during periods of rapid technical change, where peers and site practice may not reflect the latest technology or approaches and it, therefore, provides poor preparation for the LCT (Evans and Stroud, 2014). Given the need for technical change to help achieve the LCT, the OSAT model may not be as appropriate as offsite, classroom based training to ensure innovation. This suggests that the current training models may need to be overhauled in order to meet the demands of the LCT. This could mean that, in addition to scaling up the training system, there may need to be a revision to the training infrastructure and qualifications, as well as a retraining of the trainers. This, in turn, will require government funding and the introduction of appropriate policy which could be a slow process and create lags in the provision of skills.

However, July 2016 saw a response to an earlier independent review of technical education in the UK (Sainsbury, 2016) whereby the Government committed to reduce the number of vocational qualifications and streamline the vocational education and training (HM Government, 2016). The implications for the construction sector and in particular the already levy funded CITB and ECITB is still unclear. The Government strategy might address the numerical demand by increasing training, but it is unlikely to address the bottleneck issues which are dependent on specialist qualifications which may be side-lined by the emphasis on generic skills.

6.7.5 Impact of licensing

A key measure to ensure standards of installation of small scale renewables has been the Microgeneration Certification Scheme (MCS). This ensures that the installers have appropriate qualifications and quality systems in place in order for the installation to access the subsidy mechanisms (MCS, 2013). While the Green Deal was still operating a similar licensing process of appropriate qualifications and quality systems was in place to maintain standards and build consumer confidence (Jagger et al, 2014). However, there is concern that this approach to skills and competence, with the required training and required registration fees, could act as a deterrent to obtaining other low-carbon skills (Jagger et al., 2014). There are in fact signs of accreditation fatigue, as an evaluation of an offer of free training in low carbon skills found:

> *"Even where people believed there may be more funding available, if this came with greater complication and paperwork they were disinclined to do this. This may be part of the reason for skills shortages in the area – many trades simply don't feel that the costs of undertaking the training opened up sufficient new opportunities to make it worthwhile." (CSE, 2016, p:3)*

This problem is compounded by uncertainty that these licensing policies will be maintained, given the recent history of multiple cutbacks of grants and removal of subsidy schemes (Keep, 2014). This has already led to a reluctance to obtain generic low-carbon qualifications and an increasing reliance on manufacturers training schemes whenever qualifications are sought. (Mayhew and Keep, 2014) Therefore, any future training programme put in place to meet the growing demand for microgeneration and domestic low-carbon technologies will need to take into account the problems surrounding these licensing schemes. In particular, there will need to be efforts to overcome the current reluctance to engage with the low-carbon licensing schemes. This will probably require greater subsidies and funding for training in the area.

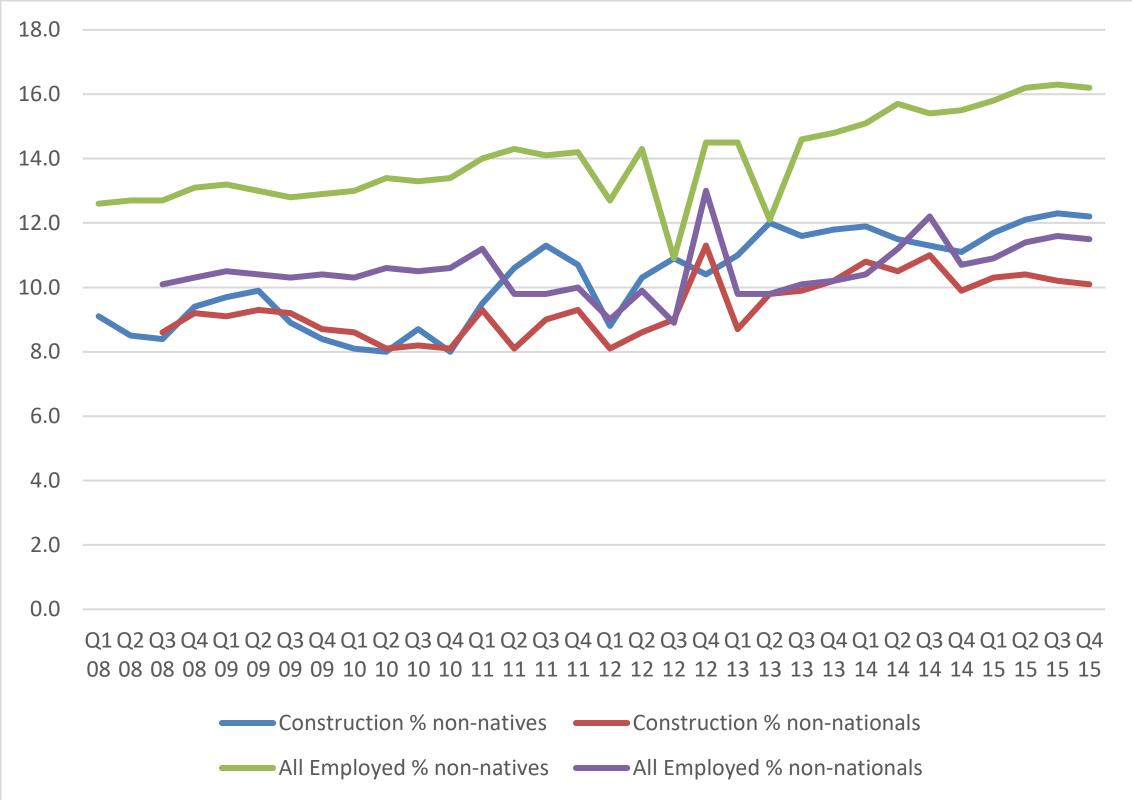
6.7.6 Limits to migration

In the past, the UK has depended on skilled migration to address construction skills shortages (Chan et al., 2008). This subsection aims to examine the potential for economic migration to meet any future construction skills shortages.

It is difficult to establish the extent to which the construction sector is currently dependent on migrants. However, the Labour Force Survey (LFS) includes variables on reported country of birth and reported national identity. That means it is possible to identify the proportion of construction workers born outside of the UK and those with non-UK national identity. Neither of these variables necessarily definitively identifies migrants, but they do provide indicators of migration within the construction workforce.

Figure 6.6 shows the percentage of the overall workforce and the construction workforce that are non-natives, or those born outside the UK, and non-nationals who identify with a nationality outside of the UK. The data is based on quarterly LFS data from the first quarter of 2008 to the second quarter of 2015. However, the data should be treated with caution. Long consistent trends are significant, but quarter-on-quarter change can be down to sampling and weighting errors or seasonality. For example, the major gyrations in the data for 2012 possibly reflect changes in the weighting or phrasing of the questions.

Figure: 6.6: Non-natives and Non-nationals as a percentage of the workforce and construction workforce



Source: Own analysis of the Labour Force Survey

Despite these cautions, it is clear that there has been a long-term, but gradual trend for more non-natives and non-nationals in the UK workforce, in general, as well as specifically in the construction workforce. Interestingly, there are proportionally fewer non-natives and non-nationals in the construction workforce than in the workforce in general. This probably reflects the greater dependence of some sectors, such as the NHS, on migrant labour.

A more detailed examination of the countries of birth shows that the construction sector has a higher proportion of Irish and Polish born workers than the whole working population. The long-standing political debate about Britain's membership of the European Union could, therefore, pose a problem for the construction sector and other migrant dependent sectors which policy makers need to take into consideration if construction demand for the LCT is to be met.

Overall, the construction sector potentially could utilise more migrants, but there remain the political and social controversies relating to a greater migrant population (Green, 2015). Equally, countries that could supply skilled construction workers, such as Poland, could in the future also be engaged in their own national LCTs, which might limit the scope for these countries to send migrants. Potentially, this suggests that about 10 or 12 percent, from the LFS of the current construction workforce born in EU countries, could need to be replaced by UK nationals who will also require training. This, in turn, could have consequences on the skills requirement to meet the needs of the LCT and again need to be taken into account in by both institutions and policy makers.

6.8 Impact of policy on the low-carbon transition

This chapter has discussed the potential scale of other policy-led options that could compete for limited construction skills and potentially distract effort from the LCT, such as adaptation to climate change and new builds to meet UK housing shortages. Some of these, such as the complete protection from excess rainfall and rising sea-levels, might be too expensive to be fully implemented. Others, such as the electrification of the railways, are essential for the LCT but have not been quantified here.

Policy choices, such as the pattern of taxation used for many construction employees, could also influence the scale and nature of construction sector training by influencing the structure of the sector (Behling and Harvey, 2015). Equally, the more direct impact of construction regulations could influence the scope for construction innovation for many years in the future (Beerepoot and Beerpoot. 2007). Other policy choices could have significant impacts on the sector and its ability to deliver the LCT.

Furthermore, future UK policies relating to training and construction skills could directly or indirectly influence the pattern of technology adoption and influence the willingness of individuals to seek and obtain specific construction training. Therefore, future UK policies aimed at training need to be carefully co-ordinated with technical choices and the underlying dynamics of the construction industry if the LCT is going to proceed without disruption. This issue and the inter-relationships between industry dynamics, technical change and policies are explored in more detail in Chapter 7.

The next chapter draws together the implications for the forecast demand for construction employment from Chapters 4, 5 and 6 and discusses the policy implications. In particular, Chapter 7 focuses on how to put in place an appropriate training regime. Additionally, it will address the patterns of skills governance, such as licensing schemes and skills forecasting, to examine how changes to governance can aid the process of ensuring that there are sufficient, appropriately skilled construction workers in place to achieve the LCT.

7 – Conclusion and Discussion

7.1 Introduction

This chapter draws together the theoretical and empirical contributions from the preceding chapters in order to better answer the primary research question of the thesis, which is:

"Could construction skill shortages disrupt the low-carbon transition in the UK?"

The answer to this question is complex and depends on the co-evolving interactions between three evolving sub-systems. These interacting components include: the patterns of economic growth; technical change – primarily the technologies and combinations of technologies used to achieve the LCT; as well as the government aimed at the LCT; adaptation to climate change and the policies towards construction skills and training. The thesis puts forward this new approach, a theoretical model of skills provision, in Chapter 3. This new model is then used to provide the basis of the following empirical chapters. Each of these three chapters addresses one of the proposed tripartite drivers of skills shortages. As there are currently no existing detailed occupational forecasts associated with the LCT, and no occupational forecasts over the extended period of the LCT, a focus of these empirical chapters is to provide such forecasts. These forecasts are based on long-term economic trends, and employ a new statistical approach, in Chapter 4. There are forecasts of the employment and occupational consequences of low-carbon technologies in Chapter 5. In addition, Chapter 6 provides estimates of potential supply of skills and additional employment forecast as a result of adaptation measures and other institutionally driven issues. On the basis of these empirical findings the thesis then examines the policy implications for the LCT.

7.2 Main findings

In order to address the primary research-question the thesis needed to establish the critical role of the construction sector for the achievement of the LCT and the structural weaknesses of the sector that mean that this could be problematic. Then, in order to structure the analysis, a theoretical approach to the drivers of skills demand was developed. This was followed by forecasts of the economically driven, technical change driven and policy driven demands for construction labour. These forecasts, combined with assumptions about the nature of the change, were then used to predict the skills profiles required in the future. Finally, the potential capacity of the economy to provide the required labour and skills was examined. The following subsections provide more details of the results of these exercises.

7.2.1 Summary of theoretical arguments

The low-carbon transition will be an important element in achieving the target of only allowing global temperatures to rise by less than 2 percent, as set by the 2015 Paris Agreement. The thesis argues that the construction sector has a critical role in building and installing the necessary low-carbon infrastructure. The results of the analysis show that the capacity of the construction sector to train sufficient new recruits is limited by its response to business cycle downturns and also the fragmented structure of the sector. The domination of the UK construction sector by sole-traders and micro firms limits its capacity to provide training or take on apprentices. In addition, this structure is also shown to be associated with low rates of innovation. However, technical and social innovation is essential in order to address the demands of the LCT.

Chapter 3 provides a new tripartite model that examines the drivers of skills shortages, especially those impacting on the LCT. The model uses three co-evolving drivers of skills demand. These three drivers are: underlying activity change; technical change, and institutional or policy change. It is argued that imbalances between the various drivers could lead to skills shortages. An analogy of the new forecasting model is to view it as a three-legged stool, each leg representing one of the drivers of skill shortages. Thus, if one leg falls behind the other drivers, it causes instability and skills shortages emerge. These are broad concepts and the interactions within and between each driver are complex. Co-evolving systems are inherently complex and, as suggested, this can give rise to problems with existing forecasting approaches for the construction sector. Varying levels of underlying growth in the wider economy impact on the level of activity by the construction sector. Similarly, patterns of technical change, in particular the technologies selected to address the LCT, will influence the nature and extent of any additional construction employment. Likewise, policies can drive additional and competing demands for construction labour, as well as influencing the scale and nature of the supply of construction workers. However, by using the tripartite model, each of the three sub-systems can be examined separately, allowing subsequent policy implications to be drawn. The main discussion of the interactions of the sub-systems, and their consequences, occurs after the three individual sub-systems are examined.

This model although specifically developed to address the skills issues relating to the LCT can be used to understand the drivers of skill demands more generally. Equally, XXXX

7.2.2 Demand

The approach used to determine demand for the numbers of construction workers, and the skills required, followed the standard forecasting techniques with adjustments that account for the longer than normal period that the forecasts needed to be made given the duration of the LCT. The numbers were determined by forecasting the future construction costs and then translating these costs into the required number of workers, taking into account potential productivity improvements over the period of the LCT. The tripartite model is then used to structure the analysis of the demand forecasts.

Underlying growth

An economic forecast was developed using Multi-channel Singular Spectral Analysis (MSSA) which allowed the impact of plateauing of population growth and educational attainment to be accounted for. This forecast was compared with the limited number of other long-term forecasts of GDP growth. The new MSSA forecast produced a lower level of growth and, correspondingly, a lower level of underlying construction growth. The MSSA forecast level of required new construction employment was similar to the level of future growth in labour market entrants shown in other forecasts. This suggests that current policies and practices should be sufficient to meet the future underlying demand. However, in contrast, using the higher levels of long-term economic growth, produce higher demands for construction labour which would be challenging to sustain.

In summary, the key finding of Chapter 4 is that the probable pattern of underlying UK economic growth is unlikely to cause construction skill shortages. Therefore, the analysis of the economic driver, the first leg of the proposed tripartite model suggests that, on the basis of growth forecasts alone, construction skills shortages are unlikely to disrupt the LCT over the long-term. This is independent of any shorter term problems associated with the business cycle.

However, as previously stated, the drivers of skills shortages are complex and depend on co-evolving interactions. Therefore, having examined the economic trends, the thesis sought to forecast the impact of technical change on skills demand in the construction sector, the second driver of the tripartite model.

Technical change

In order to achieve the UK's low-carbon future, large-scale change in technologies for power generation and use will be needed. However, there are currently no detailed forecasts of the impact of LCT driven technical change on employment in the construction sector, only forecasts of capital costs.

It is still uncertain as to which technological pathway the Government intends to support. This uncertainty currently adds to the reluctance of construction sector employers and individuals to commit to training that is specific to one pathway or another. Therefore, to better understand the impact on the workforce of the choice of technologies and to inform policy decisions, four differing DECC pathways were explored in Chapter 5.

The chapter introduces a new forecasting method that translates the predicted capital costs by technology into employment figures and skills profiles depending on the construction subsector involved. The forecast method is based on data on employment and occupations for the construction subsectors that will be responsible for implementing the various low-carbon technologies, using the DECC 2050 pathways that are examined in detail in Chapter 5. These pathways propose differing technical strategies, using bundles of the low-carbon technologies that will be needed to achieve the UK carbon reduction targets, as outlined below.

Table 7.1: Maximum Additional Construction Workers from DECC 2050 Pathways

	Maximum Additional Demand above the 2014 Workforce	2050 Percentage of 2014 Workforce
Core economic growth	191,000	8.9%
Additional Employment due to Technical Change		
Friends of the Earth, maximum in 2050	372,000	17.4%
High Nuclear, maximum in 2050	301,000	14.0%
National Grid, maximum in 2050	298,000	13.9%
MARKAL, maximum in 2050	275,000	12.8%

Source: Analysis in Chapters 4 and 5

The results of these construction employment forecasts indicate that the pathways would require additional workers within a range of between 275,000 for the MARKAL pathway and 372,000 for the Friends of the Earth pathway. The results from Chapters 4 and 5 are synthesised in Table 7.1 to illustrate the additional number of construction workers that would arise as a result of implementing a range of different low-carbon pathways. It shows the results of differences in costs between the pathways and differences in the occupational profiles of construction workers involved in building or installing the technologies deployed within the pathway.

The findings also indicate that the increases in construction employment demand associated with the LCT over the period of the transition, when translated into percentages of the existing workforce, range between 12.8 and 17.4 percent of the 2014 workforce. The calculated impact of technical change shown suggests that the predicted growth should be achievable if there is a constant slow rate of growth in the sector. The rates of growth needed are comparable to the rates commonly achieved in the short term when construction moves out of recession. However, to sustain these levels of growth over a longer period to achieve the LCT may require policy interventions and these are discussed in the next subsection.

Competing policy demands

The thesis discusses two areas where policies could impact on the ability of the construction sector to deliver the LCT. The first area examined is the additional, and competing, demand that various policies could create. The second policy area discussed is the ability of policies and institutions to supply the numbers and skill mixes of construction workers required. The second aspect is covered later in the section on supply, while this section covers the additional demands.

Table 7.2 brings together the forecasted additional aggregate construction employment from a range of policies that will be needed to adapt to the effects that higher rainfall, increased storms and rising sea levels could produce. These environmental 'adaptation' policies produce, at peak, an additional demand of between 5.5 and 19.6 percent of the 2014 construction workforce. Additionally, the option to build an extra 240,000 dwellings each year to meet the demand for housing is forecasted to produce an extra demand equivalent to 3.9 to 4.6 percent of the 2014 construction workforce.

Table 7.2: Policy Driven Additional and Competing Construction Demand Scenarios

	Maximum Additional Demand above 2014 Workforce	Percentage of 2014 Workforce
Core economic growth	191,000	8.9%
Additional Employment due to Policy Options		
Adaptation to Land and Sea Flooding		
National Enterprise Scenario, maximum in 2030	419,000	19.6%
World Markets Scenario, maximum in 2030	418,000	19.5%
Global Sustainability Scenario, maximum in 2030	123,000	5.7%
Local Stewardship Scenario, maximum in 2030	118,000	5.6%
Meeting housing demand, 240,000 houses / year		
All private		
All public	99,000	4.6%
Current mix	83,000	3.9%
	98,000	4.6%

Source: Analyses in Chapters 4 and 6

The extent and nature of the adaptation interventions required is still unclear and needs further research, as this will influence the pattern of demand. However, the extent of sea level rises and the intensity of storms and rainfall is now forecast to be worse than climatologists predicted which were the basis for the lower expenditure scenarios used here to calculate the employment figures. At the same time, cheaper approaches to environmental adaptation are being proposed Although the overall costs have yet to be detailed these technical advances should have lower employment consequences, which would offset some of the higher employment demand associated with the increased demand on construction to meet the higher levels of adaption now forecast.

Nevertheless, this additional demand on UK construction to address and adapt to the consequences of climate change, in addition to the other potential drivers of demand for construction workers, could create debilitating skills shortages. These, in turn, could disrupt the LCT and change the pattern of construction skills demanded. Adaptation to climate change is identified as mainly demanding civil engineering skills in Chapter 6. These specific skills implications of the pattern of aggregate demand are explored in the next section.

7.2.3 Skills implications

Using the nature of the construction contractors involved in the various technologies, and patterns of future demand, the aggregate labour forecasts were extended to provide details of the specific occupations that were likely to be involved in delivering the LCT and adaptation in Chapter 5. The key finding from these occupational forecasts is that the different pathways each require different patterns of skills. The analysis shows that civil engineers and electricians, as well as plumbers, heating and ventilation skilled trades will be particularly in demand across all the pathways (Table 5.14 in Chapter 5). However, the data from Chapter 5 shows that most of the additional skills required to implement this technical change will be available from the underlying pool of construction sector workers. It should be noted that an exception is the additional demand for civil engineers, which results show would not be met from the construction sector. This has training and recruitment implications, particularly for higher education which provides the initial training of most civil engineers. Equally, potential problems in the additional demand for refrigeration and heat-pump engineers is identified. These will arise as a result of the heating market moving from gas-fired heating systems to electric-powered heat-pump systems in all the pathways.

To further enrich the information around skills and the LCT for policy makers, the thesis introduces the concept of occupational skills ‘bottlenecks’, where skill shortages disrupt the LCT. These are defined as smaller specialised occupations, with relatively long training periods, or those that require significant experience. The definition also requires that these bottleneck occupations should not have large pools of the workers within, or outside of, the construction workforce that could be drawn on in the face of shortages. The Labour Force Survey was used to identify these potentially problematic bottleneck occupations within construction. The analysis indicates that these potential bottleneck occupations is likely to include: chartered surveyors; housing officers; estimators, valuers and assessors; welding trades; pipefitters; and steel erectors. This suggests that these occupations should be a focus for policy makers.

Another significant finding from the bottleneck analysis is that the high nuclear pathway is more dependent on specialist, and potentially bottleneck, skills such as welders and pipefitters. The analysis also shows that the high nuclear pathway requires more geographically concentrated and specialised construction skills. This is of particular note as it has labour relations consequences and also the potential for skills shortages. In contrast, the results show that the Friends of the Earth pathway uses skills that are available elsewhere, such as electricians and heating and ventilation engineers. Additionally, it indicates that some of the work required for the Friends of the Earth pathway could be incorporated into the normal cycle of heating equipment replacement and domestic and commercial building repair and maintenance, which would reduce the additional labour required by this pathway. However, one point of note is that, with its greater reliance on wave and tidal power, the results show that the Friends of the Earth pathway will have a greater demand for civil engineers, with its concomitant training implications. Equally, the MARKAL pathway, with its high dependence on unproven and novel technologies such as carbon capture and storage, could easily see cost overruns and require more labour. Meanwhile, the National Grid pathway depends on commercial interests which might lead to coordination problems, resulting in competing demands for limited skills.

Overall, the thesis develops a theoretical model to represent the co-evolving drivers of skills shortages, and then uses the model to underpin new forecasting approaches to identify potential skills problems that may disrupt the LCT. The results illustrate the employment and occupational consequences for the construction sector for each of the proposed DECC pathways and a range of policy driven scenarios. Combining these allows a better understanding that can inform policy makers, employers and individuals seeking careers in the construction sector. For example, the Friends of the Earth and MARKAL pathways are shown to draw more on existing skills than others, whilst the high nuclear and National Grid pathways show a possibility for disruptive skills bottlenecks. Clearly, policy makers and the other actors need to consider these skills issues when determining which pathway to adopt.

In addition to this, Chapter 5 shows that the construction sector is particularly dependent on intermediate level skills. This is of consequence, as this could be another potential problem, since this level of educational attainment is forecast to decline over the LCT period. With more people going to university, there will be fewer people who only have intermediate level qualifications.

To further enrich the forecasts for policy makers, in addition to analysing the numbers of construction workers needed, the specific occupations required by the LCT are examined in Chapters 4,5 and 6. The breakdown by occupation is dependent on the type of technologies adopted by the LCT, the extent of adaptation to extreme weather events and whether or not the UK builds the required number of dwellings for the population.

The preceding chapters provide detailed occupational breakdowns for four DECC pathways, and a range of policy driven scenarios, which could be combined in many ways, each with different employment and occupational implications. A summary of these results showing the combination that has the minimum employment impact and the combination that has the maximum employment impact is provided below.

Table 7.3 draws together the impact of underlying economic growth, the DECC MARKAL pathway, the cheapest and least labour intensive pathway, and the minimum adaption scenario as a plausible minimum overall construction sector demand. This shows that overall the minimum bundle foresees a 28.7 per cent increase on the 2015 construction employment figures by 2050. However, the occupational breakdown shows that even within this overall increase some occupations are forecast to decline. The largest declines are in back office staff, with a 11.7 per cent decrease in book-keepers and payroll managers and a 11.9 per cent decrease in personal assistants. More interestingly, the largest increase forecast over the period of the transition, is in other elementary and unskilled occupations, with a 240 per cent increase. This this reflects the importance of civil engineering for the LCT and the dependence of the subsector on this type of labour. The importance of civil engineering for the LCT and adaptation measures is also reflected in the forecasted increase in the number of civil engineers by 75.9 per cent. Parallel with the increase in civil engineers, there is a 92.8 per cent increase in other professional occupations forecasted over the LCT, reflecting a general professionalization of the sector as the proportion of graduates in the sector increases. Amongst the skilled trades, two occupational categories stand out in terms of increased demand. These are air-conditioning and refrigeration trades and plumbers and heating and ventilation trades, reflecting the importance of these trades as installers of new low-carbon heating systems. These results imply areas of policy focus for the skills institutions.

The accompanying Figure 7.1 shows the occupations with the largest and smallest percentage change between 2015 and 2050 under the minimum construction occupational demand pathway and scenario combination.

Table 7.4 provides a contrasting occupational profile, showing the maximum combination of the most expensive and labour intensive DECC pathway, the Friends of the Earth’s high renewables pathway, plus the more intensive climate change adaptation profile, together with the addition of the results of a housing programme to build 240,000 extra dwelling per year. This profile is the maximum feasible combination and, even then demand, is very unlikely to be this high. Overall, this bundle of construction activity creates 49.3 per cent extra construction jobs. As with the minimum profile, there is an emphasis on other elementary and unskilled occupations, as well as civil engineers, with increases of 299.9 per cent and 178.9 per cent respectively. Clearly, again there are significant policy implications if demand is to be met.

This scale of increase in civil engineers who require a graduate level training could be difficult to achieve without sustained policy interventions. Other areas of concern include ‘other process plant and operatives’ who show a 179.8 per cent increase in demand and ‘other professional occupations’ with a 139.7 per cent increase, which are likely to have training implications for the skills institutions.

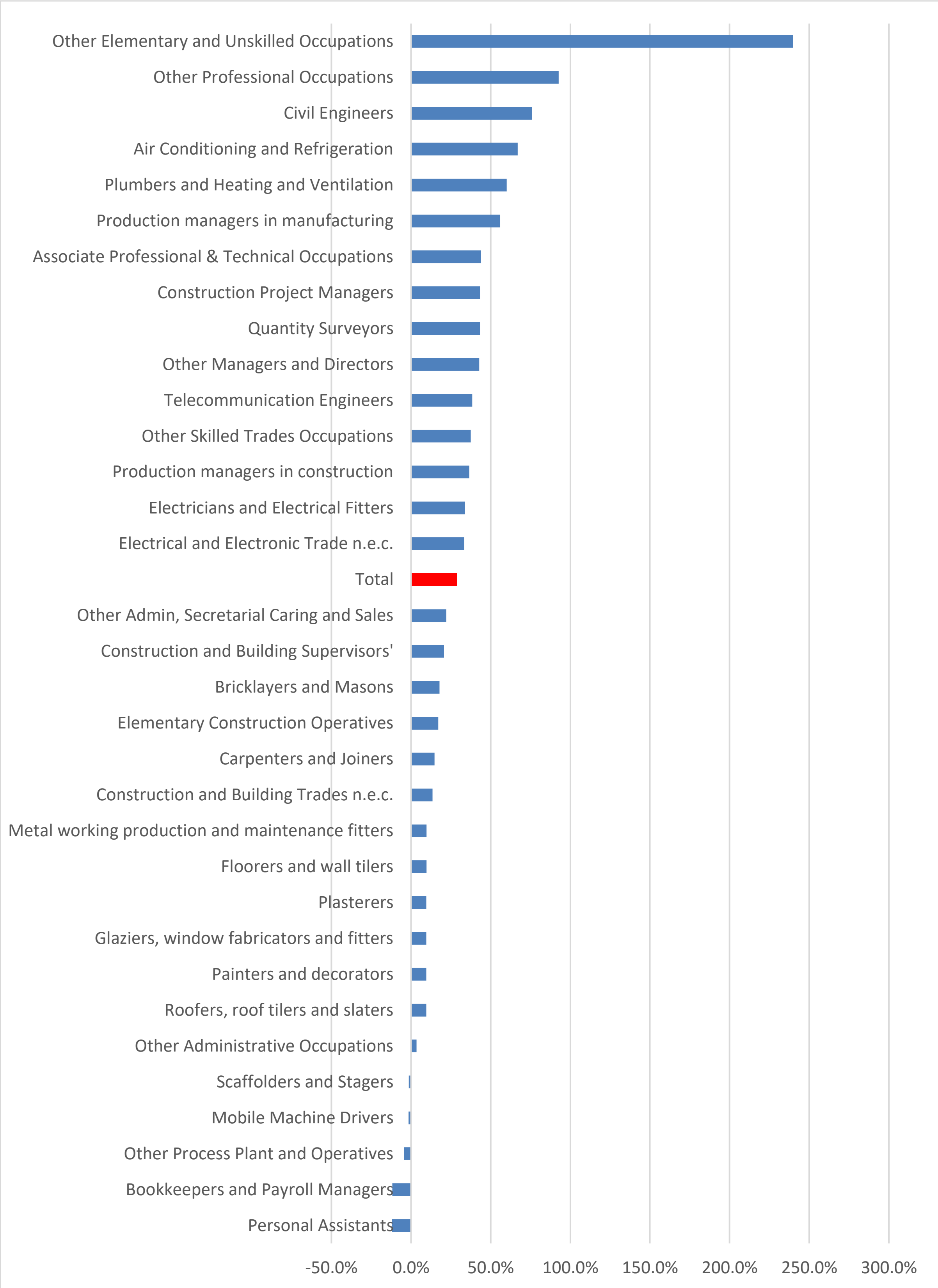
The accompanying Figure 7.2 provides the profile of occupational increase between 2015 and 2050 for the maximum combination of pathways and scenarios.

Table 7.3: Minimum 2050 Construction Occupational Demand

	2015 Baseline	2050 baseline	MARKAL	Adaptation Global Sustain-ability	Minimum Aggregate demand	Percentage Growth on 2015
Production managers in manufacturing	25,246	31,000	6,100	2,300	39,400	56.1%
Production managers in construction	126,970	156,000	10,300	7,100	173,400	36.6%
Other Managers and Directors	77,092	94,800	10,200	5,100	110,100	42.8%
Civil Engineers	30,587	43,800	**	10,000	53,800	75.9%
Quantity Surveyors	26,179	37,500	**	**	37,500	43.2%
Construction Project Managers	38,881	55,700	**	**	55,700	43.3%
Other Professional Occupations	90,164	129,000	25,900	18,900	173,800	92.8%
Associate Professional & Technical Occupations	118,861	146,600	12,600	11,900	171,100	43.9%
Bookkeepers and Payroll Managers	26,962	23,800	**	**	23,800	-11.7%
Other Administrative Occupations	42,312	37,300	6,500	**	43,800	3.5%
Personal Assistants	20,203	17,800	**	**	17,800	-11.9%
Other Admin, Secretarial Caring and Sales	71,348	62,800	15,500	8,800	87,100	22.1%
Metal working production and maintenance fitters	20,679	22,700	**	**	22,700	9.8%
Air Conditioning and Refrigeration	12,214	13,400	7,000	**	20,400	67.0%
Electricians and Electrical Fitters	132,933	145,700	32,300	**	178,000	33.9%
Telecommunication Engineers	15,321	16,800	4,400	**	21,200	38.4%
Electrical and Electronic Trade n.e.c.	13,940	15,200	3,400	**	18,600	33.4%
Bricklayers and Masons	65,929	72,200	5,500	**	77,700	17.9%
Roofers, roof tilers and slaters	38,718	42,400	**	**	42,400	9.5%
Plumbers and Heating and Ventilation	135,751	148,900	68,300	**	217,200	60.0%
Carpenters and Joiners	201,012	220,300	10,400	**	230,700	14.8%
Glaziers, window fabricators and fitters	21,254	23,300	**	**	23,300	9.6%
Construction and Building Trades n.e.c.	197,877	216,900	7,800	**	224,700	13.6%
Plasterers	45,515	49,900	**	**	49,900	9.6%
Floorers and wall tilers	35,996	39,500	**	**	39,500	9.7%
Painters and decorators	83,935	92,000	**	**	92,000	9.6%
Construction and Building Supervisors'	39,855	43,700	**	4,400	48,100	20.7%
Other Skilled Trades Occupations	68,366	52,300	24,100	17,600	94,000	37.5%
Scaffolders and Stagers	25,058	24,700	**	**	24,700	-1.4%
Mobile Machine Drivers	27,754	27,300	**	**	27,300	-1.6%
Other Process Plant and Operatives	59,628	41,600	15,400	**	57,000	-4.4%
Elementary Construction Operatives	140,227	138,200	21,600	4,500	164,300	17.2%
Other Elementary and Unskilled Occupations	30,563	91,800	**	12,100	103,900	240.0%
Total	2,138,045	2,374,900	274,900	102,778	2,752,578	28.7%

Source: Chapters 4, 5 and 6

Figure: 7.1: Minimum Percentage Change Between 2050 and 2015 by Occupation



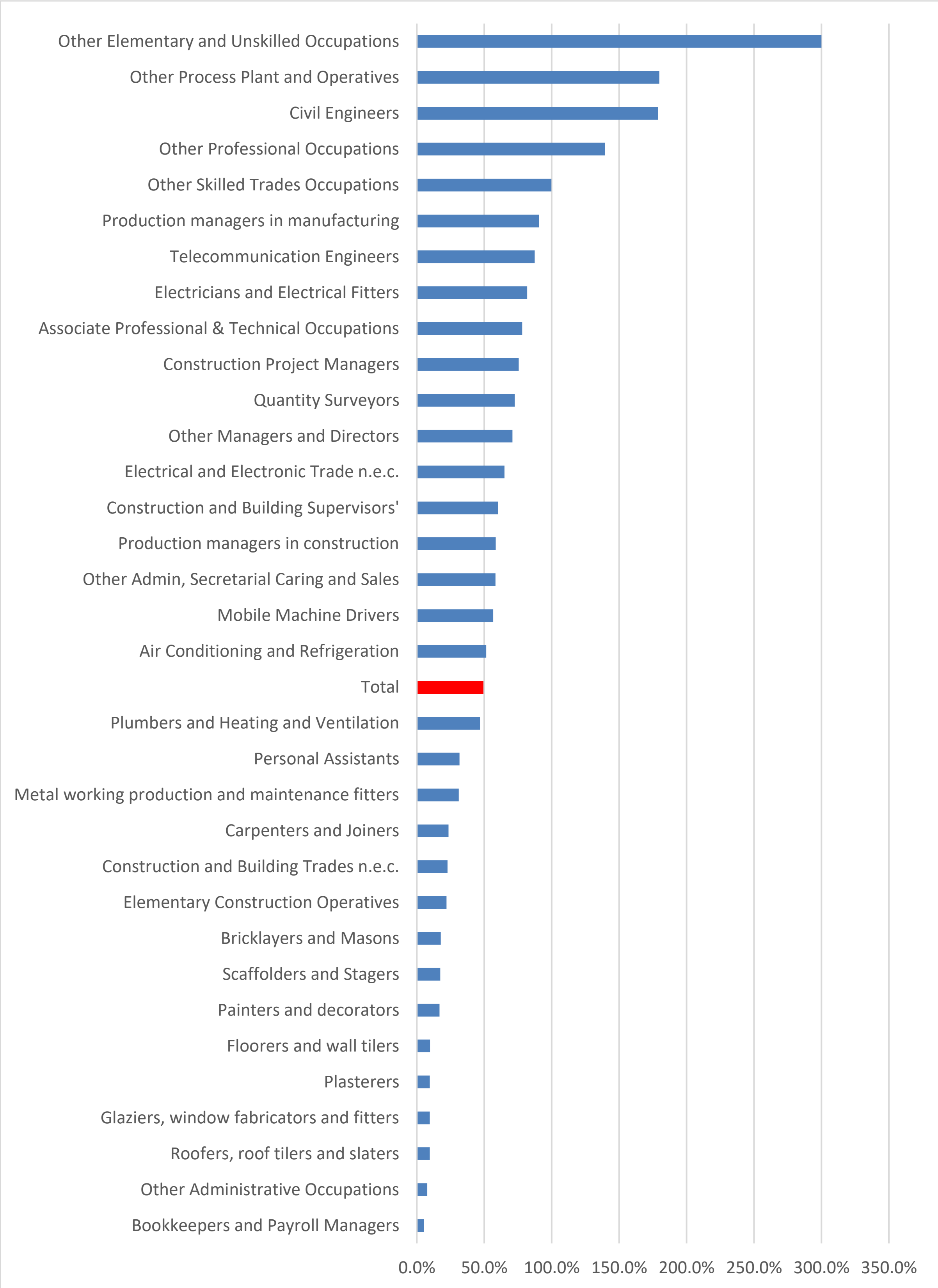
Source: Table 7.3

Table 7.4: Maximum 2050 Construction Occupational Demand

	2015 Baseline	2050 Baseline	Friends of the Earth	Adaptation National Enterprise	Additional New Build	Maximum Aggregate Demand	Percentage Growth on 2015
Production managers in manufacturing	25,246	31,000	9,400	7,700	**	48,100	90.5%
Production managers in construction	126,970	156,000	13,900	24,300	7,100	201,300	58.5%
Other Managers and Directors	77,092	94,800	15,700	17,600	3,600	131,700	70.8%
Civil Engineers	30,587	43,800	7,500	34,000	**	85,300	178.9%
Quantity Surveyors	26,179	37,500	**	7,700	**	45,200	72.7%
Construction Project Managers	38,881	55,700	4,033	8,500	**	68,233	75.5%
Other Professional Occupations	90,164	129,000	32,500	48,800	5,800	216,100	139.7%
Associate Professional & Technical Occupations	118,861	146,600	19,700	40,700	4,800	211,800	78.2%
Bookkeepers and Payroll Managers	26,962	23,800	4,600	**	**	28,400	5.3%
Other Administrative Occupations	42,312	37,300	8,300	**	**	45,600	7.8%
Personal Assistants	20,203	17,800	4,300	4,500	**	26,600	31.7%
Other Admin, Secretarial Caring and Sales	71,348	62,800	13,300	30,000	6,900	113,000	58.4%
Metal working production and maintenance fitters	20,679	22,700	**	4,400	**	27,100	31.1%
Air Conditioning and Refrigeration	12,214	13,400	5,100	**	**	18,500	51.5%
Electricians and Electrical Fitters	132,933	145,700	86,300	9,700	**	241,700	81.8%
Telecommunication Engineers	15,321	16,800	11,900	**	**	28,700	87.3%
Electrical and Electronic Trade n.e.c.	13,940	15,200	7,800	**	**	23,000	65.0%
Bricklayers and Masons	65,929	72,200	5,400	**	**	77,600	17.7%
Roofers, roof tilers and slaters	38,718	42,400	**	**	**	42,400	9.5%
Plumbers and Heating and Ventilation	135,751	148,900	50,300	**	**	199,200	46.7%
Carpenters and Joiners	201,012	220,300	8,000	7,300	12,700	248,300	23.5%
Glaziers, window fabricators and fitters	21,254	23,300	**	**	**	23,300	9.6%
Construction and Building Trades n.e.c.	197,877	216,900	4,100	7,800	14,100	242,900	22.8%
Plasterers	45,515	49,900	**	**	**	49,900	9.6%
Floorers and wall tilers	35,996	39,500	**	**	**	39,500	9.7%
Painters and decorators	83,935	92,000	**	**	6,100	98,100	16.9%
Construction and Building Supervisors'	39,855	43,700	5,000	15,100	**	63,800	60.1%
Other Skilled Trades Occupations	68,366	52,300	17,400	45,800	21,100	136,600	99.8%
Scaffolders and Stagers	25,058	24,700	4,700	**	**	29,400	17.3%
Mobile Machine Drivers	27,754	27,300	4,600	11,600	**	43,500	56.7%
Other Process Plant and Operatives	59,628	41,600	114,020	11,200	**	166,820	179.8%
Elementary Construction Operatives	140,227	138,200	10,200	15,500	7,300	171,200	22.1%
Other Elementary and Unskilled Occupations	30,563	91,800	6,100	18,600	5,729	122,229	299.9%
Total	2,138,045	2,374,900	371,700	351,178	95,243	3,193,021	49.3%

Source: Chapters 4, 5 and 6

Figure 7.2: Maximum Percentage Change Between 2050 and 2015 by Occupation



Source: Table 7.4

7.2.4 Supply

Additional demand is only a problem if supply does not match the level of demand. This is implicit in the proposed tripartite model where, normally, supply and demand coevolve as underlying demand, technical change and institutions coevolve. When any component in the tripartite system lags behind due to inertia, there is potential for imbalances and skills shortages. This subsection, which examines the probable patterns of supply, therefore focuses on where inertia and lags can enter the system and cause shortages where supply is insufficient to meet the levels of demand of the LCT.

The numbers of labour market entrants are forecast to initially decline to 2025, and increase to about 2035, and then plateau to 2050. The potential level of supply is discussed in Chapter 6 in the context of policy and skills institutions. There, it is argued that, in and of themselves, each of the potential additional demands is achievable. However, collectively this could put great stress on the skills system and, therefore, requires appropriate policy responses. Clearly, the policy interventions need to be consistent and continuous, but evolving in the light of developments.

The critical role of skills institutions in identifying potential construction skills shortages as they emerge, and adequately responding to these issues, is identified. It is evident that to meet the increasing demand of the LCT as it progresses, institutions need to identify, and then disseminate, the patterns of future skills and occupational requirements to assist school leavers, employers and others in identifying potential careers within construction. The skills institutions also need to ensure that they can provide the appropriate training as required to meet demand. Potentially disruptive lags in communicating demand and provision are especially important in areas of the construction sector with long training periods, such as welding, which could become bottleneck areas. This might mean policy interventions to provide partial or complete subsidies for training in areas deemed at risk.

The exact requirement for specific occupations is difficult to predict and therefore, formulating appropriate the interventions to ensure the required supply of workers could be equally problematic. However, if general policies aimed at improving STEM skills and encouraging vocational training were to be implemented these would have benefits in addition to meeting the construction demands of the LCT and adaptation. Within higher education, the clear additional demand for civil engineers needs to be addressed by policy makers, without diluting the quality of the graduates produced.

Furthermore, the analysis of migrants within the construction sector has revealed that the sector is less dependent on migrants, measured in terms of non-nationals and non-natives, than the UK economy as a whole. However, the analysis has revealed that sector is particularly dependent on Irish and Polish workers. In contrast, the sector employs fewer Black and Asian ethnic minorities than other sectors. The restrictions on EU migrant workers into construction might become particularly problematic in the context of the June 2016 referendum vote for the UK to leave the European Union – Brexit and may require migrant policy changes Finally, the analysis shows that, approximately, only one in ten of construction workers are female. This suggests areas for additional recruitment, where there is a need for appropriate policy in order to boost supply by helping to make the sector can become more attractive to women and ethnic minorities.

7.3 Policy implications

A key feature of a co-evolving system is the potential for complex and unexpected interactions to cause disruption. This means, for the proposed tripartite model, that non-dynamic and non-evolving policy options are unlikely to be effective and there is a need for 'agile' policy making (Room, 2011). In turn, this requires constant monitoring of the system to establish where problems are emerging to allow the issues to be dealt with. Chapter 6 identified three key areas where policy makers need to concentrate.

Firstly, chapters 5 and 6 established the need for policy certainty relating to the choice of technological components of the infrastructure needed for the LCT as a critical feature required for securing finance. Such certainty enables and reinforces efforts to invest in training and recruitment to obtain LCT specific skills. Without certainty over the policy choices, it is highly likely that critical occupations, especially technology specific occupations, will be in shortage and cause bottlenecks in the implementation of the LCT. This will be particularly the case where these occupations have no widespread use beyond the LCT.

Secondly, Chapter 5 indicated that the different technology bundles for achieving the LCT had differing skills and occupational profiles. For instance, the High Renewables pathway largely involves electrical and plumbing skills, which are already within the domestic dwelling construction and repair sector. However, the High Nuclear pathway requires specialised and highly localised skills that only partly can be drawn from the civil engineering sector. Therefore, the research findings suggest that issues of skills need to be included in the consideration of which technologies are adopted and the timing of their introduction. This is in order to ensure that the differing skills requirements of the different technologies are calculated and adequate training and policies are in place to avoid the potential for the emergence of critical skills shortages.

Thirdly, another critical issue that arises from the analysis in Chapter 6 is the conflicting demand of attempting to undertake the LCT at the same time as addressing the negative impacts of climate change that are already in progress, through large-scale adaptive measures such as flood prevention. Both require large inputs from civil engineering companies and this would mean a high demand for civil engineers and specialist managers and operators of construction equipment. Again, this will require policy interventions aimed at Higher Education to ensure sufficient recruitment and initial training.

Chapter 6 also examined the responsiveness of the UK skills policy system to the drivers of construction training demand. An important problem arising for those deciding to fund or to undertake appropriate training specific to the LCT was found to be the level of uncertainty about the technologies that would be supported and adopted in the UK to provide low carbon energy. Various studies, cited in Chapter 3, suggest that uncertainty means that people are more likely to undertake training in traditional technologies which have a proven demand. This, combined with demographic changes identified in Chapter 4, will mean a declining number of new entrants to the labour market, particularly those willing and able to obtain a vocational qualification. This, combined with an increasingly fragmented structure of the UK construction labour market, discussed in Chapter 2, with more sole-traders and micro-firms, could lead to a reduced entry into skilled trades.

In terms of future policies Chapter 6 also indicated that the business cycle, with its impact on recruitment, training and the loss of experienced workers, would have a negative impact on the ability of the construction sector to deliver the LCT. This finding is of note as it indicates that a potentially remedial measure of promoting publicly-funded building projects during economic downturns could maintain the momentum of the construction sector and reduce the negative impacts of business downturns.

In summary, based on the above discussion, the recommendations for future government policy interventions to avoid potentially disruptive skills shortages are as follows:

- Funding training in specific areas, especially those considered to be potential bottleneck occupations.
- Support for university training of civil engineers, especially focusing on skills needed for flood prevention and tidal barrages.
- Greater support for ethnic minorities and women to enter the sector, especially as electricians and plumbers.

- Improved innovation support for heat-pump technologies to make installation more of a plug and fit operation.
- Overall, greater career certainty and constant monitoring and evaluation of the construction labour market remains the most important policy options.

7.4 Implications for future research

The research findings have shown that the pattern of skills demand needs to be continually reassessed as the LCT develops, in order to avoid disruptive skill shortages and specific occupational bottlenecks. Uncertainty over the choice of long-term technical change pathway to be adopted has been shown to be another key issue. The inherent complexity of the skills system means that there is an urgent need for a commonly agreed LCT pathway that can be adequately signposted by policy and support mechanisms. Since, the research forecasts showed that different technologies require similar skill profiles, there is no need for a rigid commitment to particular technologies over the long-term. However, the forecasts did find that a number of skills would be in widespread demand, some of which require long training periods. This implies that there will be a need for a clear policy commitment to certain skills that can be used over a range of LCT technologies. This firm policy commitment would then provide the level of certainty required by employers and individuals when making decisions about obtaining critical low-carbon skills.

Once the technical trajectories have been selected, there should ongoing research into the skills implications which is linked to careers advice and training policy. The research and the proposed pathway should also provide updated career guidance advice for the construction sector in order to encourage the acquisition of the required skills.

The forecasts contained in the thesis have provided more detailed knowledge about the employment and skills requirements for achieving the low-carbon transition. However, the available evidence reviewed here also suggested that adaptation could create equal or even greater demands on the construction sector than the LCT. This indicates the need for further research to characterise the impacts of climate change in terms of rainfall and rising sea levels for the UK. This then needs to be translated into greater consensus about the choice of appropriate adaption measures to mitigate these problems and the employment demand generated by them. This then needs to be analysed in alongside the demands on the construction sector by the LCT and appropriate policies put in place to avoid skills shortages

To inform policy-making, the new forecasts in the thesis have provided a breakdown of the specific skills associated with LCT technical change pathways for the first time. However, more detailed research into the specific skills associated with each low-carbon technology would provide greater information about the potential risks posed by individual skill shortages and further research is recommended. Given the possibilities for the patterns of skills demand to change over time, there is a clear need for regular data collection, analysis and updating of policy.

The tripartite model can be replicated, in future years in the UK or elsewhere, when more up-to-date and hopefully more detailed information about low carbon pathways and adaptation scenarios are developed. This would provide critical information for skills policy makers to refine their response to the demands of the LCT. Equally, the empirical and theoretical model proposed in the thesis could be used in other countries with similar pathways and scenario data could be used to provide nationally specific skills demand forecasts. Despite nationally specific institutions, the coevolving interactions between economic change, technical change and institutional change should show the same features. By separating out economic change, technical change and institutional change it becomes easier to incorporate country and context specific issues.

The long-term economic forecast approach also has implications beyond the requirements of forecasting the skills demands of the LCT. The forecast has implications for social and political developments over the next fifty years, which in turn could influence the likelihood of a successful LCT. This is an area which will be actively explored in further research.

Finally, the tripartite approach to skills forecasting could be used in other fields, and in response to other challenges, to provide long terms forecasts of skills requirements. This means that the theoretical implications of the coevolving systems, and the negative impacts of component systems lagging behind the others, has general application beyond an understanding of the skills requirements of the LCT.

7.5 Concluding remarks

The thesis investigated the potential for employment demand and skills deficiencies to impact on the transition to a low-carbon economy in the UK and established construction as critical for its success. The answer to the research question:

“Could construction sector skill shortages disrupt the low-carbon transition in the UK?”

is complex and no simplistic ‘yes’ or ‘no’ answer can be deduced from the research findings. However, importantly, the research clearly indicates that the success of the low-carbon transition could be disrupted by construction sector skills shortages unless new measures are introduced to monitor the demand for skills and appropriate agile policy responses are put in place to ensure their supply. It is hoped that the new methodologies and findings of this thesis go some way to achieving these goals as well as having more general applications.

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Glossary

ABS – Annual Business Survey – The ABS, which used to be known as the Annual Business Inquiry Part 2, collects financial data from end year accounts of businesses registered for PAYE or VAT including turnover, wages and salaries, purchases of goods and services, stocks and capital expenditure.

ASHE – Annual Survey of Hours and Earnings – Annual survey covering levels, distribution and make-up of earnings and hours worked for UK employees by sex and full-time/part-time status in all industries and occupations based on a 1% sample of employee jobs taken from HM Revenue & Customs (HMRC) Pay As You Earn (PAYE) records.

BIS – Department of Business Innovation and Skills – the Government Department responsible for sectoral interests, support for research and innovation, as well as the funding higher and vocational education.

CCS – Carbon Capture and Storage – a process that captures the CO2 from fossil fuel combustion and the stores it, usually underground.

CITB – Construction Industry Training Board – A levy funded training body for the construction industry, since the levy only applies to large companies the training and qualifications provided match the needs of the large companies rather than the needs of the majority of small companies.

CO2 – Carbon Dioxide – the main greenhouse gas which is capable of remaining in the atmosphere for 1,000's of years and is the main product of burning fossil fuels.

DECC – Department of Energy and Climate Change – UK Government Department responsible for energy policy and climate change issues.

ECITB – Engineering Construction Industry Training Board – A similar body to the CITB that concentrates on technical infrastructure which have a high mechanical or electrical engineering component.

FOE – Friends of the Earth – Environmental campaign organisation responsible for one of the DECC 2050 Pathway scenarios.

GDP – Gross Domestic Product – Total Output or increase in value from within a Country often expressed in real terms or with the impact of inflation removed.

GFCF – Gross Fixed Capital Formation – a measure from the National System of Accounts used by many countries including the United Kingdom that covers investments in capital.

GVA – Gross Value Added – Similar to GDP but measured at the sectoral or regional level.

GW – Giga Watt – a unit of power output 1,000,000 times bigger than a Mega Watt.

HESA – Higher Education Statistics Agency – The body charged with collecting a range of data covering higher education including data about staff, students, qualifications obtained and the initial destinations of graduating students.

IMF – International Monetary Fund – a United Nations body that provides loans to member countries and provides monetary policy advice.

LCC – Low-Carbon Construction – the part of the construction sector and its workforce that is engaged in low-carbon building and installing low-carbon measures as part of the LCT.

LCT – Low Carbon Transition – The process by which the economy moves from high levels of CO2 emissions to low or zero levels of emissions.

LFS – Labour Force Survey – a quarterly UK household based survey which measures a range of labour market variables.

MAC – Migration Advisory Committee – a Home Office committee that advises on the occupations that are in sufficient shortage to allow immigration from overseas.

MARKAL – MARK-et AL-location a compounding of Market Allocation, reflecting the cost minimising allocation process adopted in the low-carbon model.

MCS – Microgeneration Certification Scheme – A quality system that certifies microgeneration equipment and their installation a prerequisite for various subsidy and support schemes.

MSSA – Multichannel Singular Spectral Analysis – a statistical methodology based on SSA that allows the analysis and forecasting of multiple variables and their interactions.

MVHR - Mechanical Ventilation and Heat Recovery – a system that removes stale and damp air from a building and replaces it with fresh air that is warmed using heat recovered from the exhaust.

MW – Mega Watts – a measure of power output or 1,000 Watts

N.E.C. – Not Elsewhere Classified – used in statistical classifications as a catch all category

NNLS – Non-Negative Least Square – a regression method that ensures that are the coefficients are positive.

NVQ – National Vocational Qualification – a vocational qualification consisting of a series of modules available at various levels.

OECD – Organisation for Economic Co-operation and Development – an international treaty body which operates as an international economic think tank for the richer countries responsible for many international standards and approaches to measuring R&D, Productivity and Human Resources for Science and Technology.

ONS – Office of National Statistics – the UK's national statistical office.

OSAT – On-Site Assessment and Training – a assessment and training model used by the CITB to deliver qualifications outside of colleges.

R&D – Research and Development – defined by the OECD's Frascati Manual as "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications." (OECD, 1994)

SIC – Standard Industrial Classification – an industrial classification currently based on the 2007 Eurostat Classification NACE, hence the SIC 2007.

SOC – Standard Occupational Classification – a classification of occupations which is updated every 10 years with the current classification established in 2010, hence SOC 2010.

SSA – Singular Spectral Analysis – a statistical technique that uses Fourier analysis to decomposes time series into a trend, a series of cyclic components and white noise.

SSC – Sector Skills Council – an employer supported body tasked with assessing and developing qualifications for a specific sector.

STEM – Science Technology Engineering and Mathematics – the grouping of scientific and technological educational disciplines and subjects that underpin high-technology and other innovations.

TW – Terra Watt – a measure of power output 1,000, 000 time bigger than a Mega Watt.

UCAS – Universities and Colleges Admission Service – The body that provides a central system for managing entrants and entry requirements to UK colleges and universities.

UKCES – UK Commission on Employment and Skills – a Government funded body which has oversight of the Sector Skills Councils (SSCs) and commissions employment and skills related research, notably the Employers Skills Survey and the Working Futures series of forecasts of employment, occupations and required educational attainment.

Key Data Sources

This section details the main data sources used in the thesis, additional sources were used and these are described in the text. However, the following sources were used on multiple occasions and were critical to the analysis.

Labour Force Survey (LFS)

The UK Labour Force Survey is a quarterly household based survey consistent with the European Labour Force Survey which measures a range of individual level labour market information. Designed to reliably measure unemployment levels at the sub-regional level. Quarterly data available from 1992 and accessible via the UK Data Archive. Used to provide data about the numbers working in construction and its sub-sectors as well as their educational attainment and occupations.

Quarterly Construction Statistics

The Quarterly Construction Statistics consists of two data series 'Output in the Construction Sector' and 'New Orders in the Construction Sector', the first measuring activity in the previous quarter and the second a forward-looking indicator. Both of the series are broken down by construction sub-sectors, such as domestic new-build and commercial repair and maintenance. However, these categories do not map onto any other statistical classification or data source. This problem combined with an acknowledged problem with the sampling and weighting used by the series means that although used descriptively in Chapter 2 these statistics were not used in the modelling in Chapter 3 or elsewhere.

Bank of England 300 years of data

The Bank of England's original three centuries dataset was developed to accompany a 2010 article in their Quarterly Bulletin entitled 'The UK Recession in Context: What do three centuries of data tell us?'. This was later updated in 2015 to version 2.2 and this is the version that was used to provide the real GDP, productivity and fixed capital investment data used as the basis for the economic forecast in Chapter 3.

Barro and Lee educational attainment data

Robert J Barro and Jong-Wha Lee released a dataset on educational attainment linked to their 2015 publication of a book entitled 'Education Matters: Global Schooling Gains from the 19th to the 21st Century''. The dataset provided data on the attainment levels of the 15 to 24 year-old population and the working age (or 15 to 64 year-old) population for major countries over the period 1870 to 2040 at five year intervals.

DECC 2050 Pathways

The Department of Energy and Climate Change in 2010 published a '2050 Pathways Analysis' and associated Excel spreadsheets. These spreadsheet models where subsequently updated and re-released in 2011 along with a series of pathways that enabled the UK to meet its carbon reduction targets. Four of these published pathways were used, especially the associated costs spreadsheets, to form the basis of the projections of the employment consequences of low carbon technical change in Chapter 4 of this thesis.

Working Age Population Estimates

The working age (taken to be 15 to 64 for men and 15 to 60 for women) population is based historically on UK Census data and the projections are based on Eurostat projections. The Office of National Statistics has a spreadsheet of single year age bands by gender from the 1911, 1921, 1931, 1951, 1961, 1971, 1981, 1991, 2001 and 2011 censuses this was aggregated to produce working age populations. This data was supplemented with manually extracted data from the 1939 National Register, as well as the 1851, 1861, 1871, 1881, 1891 and 1901 censuses.

Annexes

Annex A: Data Used for Economic Forecasting

The economic forecast uses four elements to forecast GDP: these are the size of the working-age population, the quality of the working age population measured in terms of educational attainment, productivity per capita as a measure of technical change, and capital investment. Each of these elements is explored below, including details of the sources used and, where necessary, any additional assumption needed to extend the available time-series.

These indicators have been selected from the available time series, as they represent some of the headwinds that Robert Gordon (2012) argues will depress the rate of GDP growth in the future in the UK. These 'headwinds' are part of a wider literature on 'Secular Stagnation' that argues that a range of factors exist that could be leading to a slow recovery from the recession and could lead to slower long-term growth (Pagano and Sbracia, 2014; Summers, 2015; Eichengreen, 2015).

The least ambiguous potential cause of secular stagnation is the 'Demographic Transition' occurring in advanced economies which sees smaller families, fewer young entrants to the labour market and an ageing workforce (Reher, 2011). Fewer young entrants, and a peaking of tertiary educational participation, also imply a reduction in growth and plateauing of educational attainment in the workforce. Therefore, since the size of the workforce and its educational quality are relatively easy to predict, and are fundamental to the long-term growth of the economy, they are selected as the predictors for the forecast.

The Capital Investment data and the Productivity per Capita data come from the previously cited Bank of England data set, in particular, version 2.2 of the spreadsheet that updates the data series to 2014. The Real GDP at Market Prices data is available back to 1700 and the Real capital investment data is available back to 1831. The educational attainment data is available from 1870 but is backcast using demographic data to 1856. However, as the Productivity per

Capita and Working Age data is only available from 1856, this is used as the starting point for the analysis.

The Gross Domestic Product (GDP) data, a 158-year time series of UK GDP from 1856 to 2014 is from a longer time series[2] from a Bank of England project (Hills et al., 2010). The GDP data used is from the Real Term Market-Based GDP series. The period was chosen to provide a balanced dataset when added to data on real term investment levels, labour productivity, the working age population and the proportion of the working-age population with tertiary level qualifications. The main limiting factor is that the first population census with usable age band data was in 1856, and this provides the basis for much of the labour market data used. The real investment data and labour productivity data also comes from the Bank of England spreadsheet. The working-age population data comes from a series of population census reports and, more recently, from National Statistics and Eurostat demographic data. Where necessary, the historical data from the censuses has been interpolated using the Stata Csipolate function at the gendered five-year age band level and aggregated up to produce the working age time series. The proportion of the working-age population with tertiary level qualifications comes from the educational attainment data associated with Barro and Lee (2015). The Barro-Lee data covers the period from 1870 to 2010 at five-year intervals. This attainment data was backcast to 1850 using ARIMA and demographic data and then interpolated to produce a continuous series using the Stata Csipolate function.

Annex A1: Working Age Population

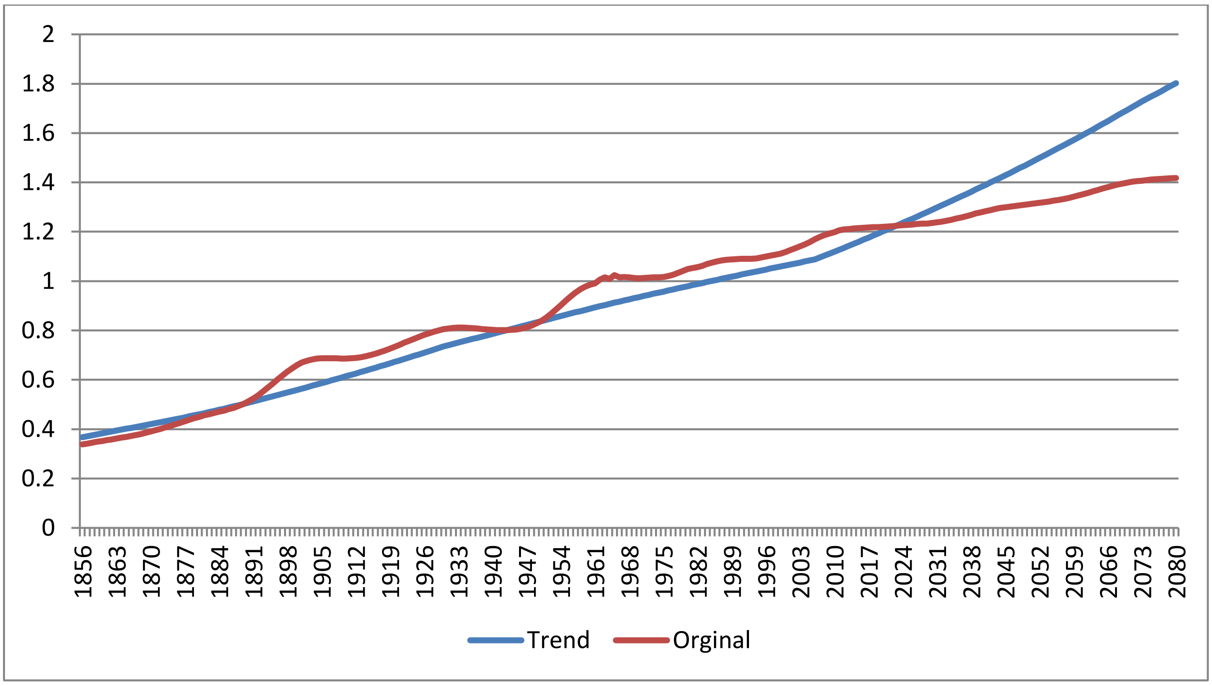
Working age population is a core underlying variable that potentially can influence the rate of GDP growth. A rapidly growing population is more likely to have a rapidly growing GDP. Using the time series created for this thesis from census data, UK National Statistics and Eurostat data

[2] Version 2.2 of the data spreadsheet is used that extends the data from the original 2009 to 2014.

a Singular Spectral Analysis was conducted. For consistency the working age has been taken as 15 years old to 65 years old. Various changes to school leaving age and retirement ages have occurred over the period and it was not the intention to account for all these changes.

Using these findings, Figure A.1 plots the working age time series and its underlying long-term trends. The graph demonstrates that that the current demographic forecast for the UK for the working age population is diverging from the long-term trend in recent years and into the future, with the population growing at a slower rate than trend and history. This clearly will have implications for the UK's future economic growth. A caution should be included about the long-term trend, as this is generated by using a moving 75-year window on the 225-year time-series. This long window is known to produce a smooth trend line and does not necessarily take account of any short term, small changes to the underlying data, especially near both ends of the series.

Figure A.1: Working Age Population Original and Long-term Trend



Source: UK Censuses, National Statistics, Eurostat and MSSA analysis

Annex A2: Tertiary Education Attainment

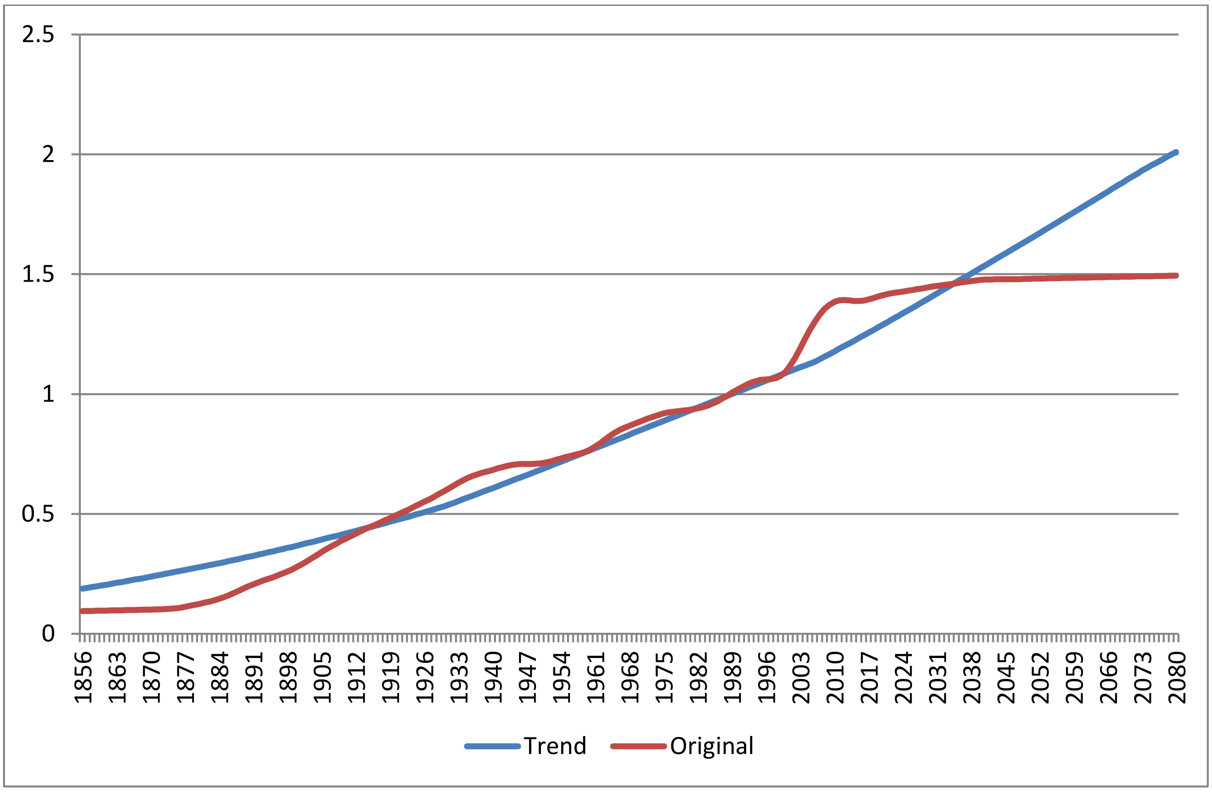
The labour market quality of the population, measured using the educational attainment of the population, is a potentially important modifier of the raw impact of a growing population. This provides a measure of the quality of the workforce and is a useful proxy for the ability to produce and adopt innovations.

A time series of the proportion of the working-age population with a tertiary level qualification comes from the Barro and Lee (2015) data for the UK. However, as this published data set only covers the period from 1879 to 2014, and only includes projections to 2040 it does not cover the whole required period 1856 -2064 used in the analysis. Therefore, the data series was backcast and forecast using the 15-24-year-old and working age (15 to 64-year-olds) population time series. The combination of a plateauing of the proportion of 15-24-year-olds with a tertiary qualification and a decline in the numbers of 15 to 24-year-olds leads to a plateauing of the proportion of the workforce with tertiary qualifications.

The results of the SSA analysis of the full data set for Tertiary educational attainment in Figure A.2 shows that 2010 represented a downwards turning point in attainment, following a period of rapid growth in the proportion of the workforce with tertiary qualifications during 2003-2010. From 2010, a much more gradual growth of attainment is shown in the following years. These findings suggest that there will be a much slower increase in the quality of the workforce in the future. This has specific implications for the low carbon transition whose success is based on innovation and growth, and will again be discussed further in Chapter 7 along with the other drivers subjected to SSA analysis

Similar cautions about using a relatively long 75-year window apply to this long-term trend analysis as with the working age series before. However, if anything, the divergence from trend is more pronounced.

Figure A.2: Proportion of Working Age with Tertiary Level Qualifications and Long-term Trend

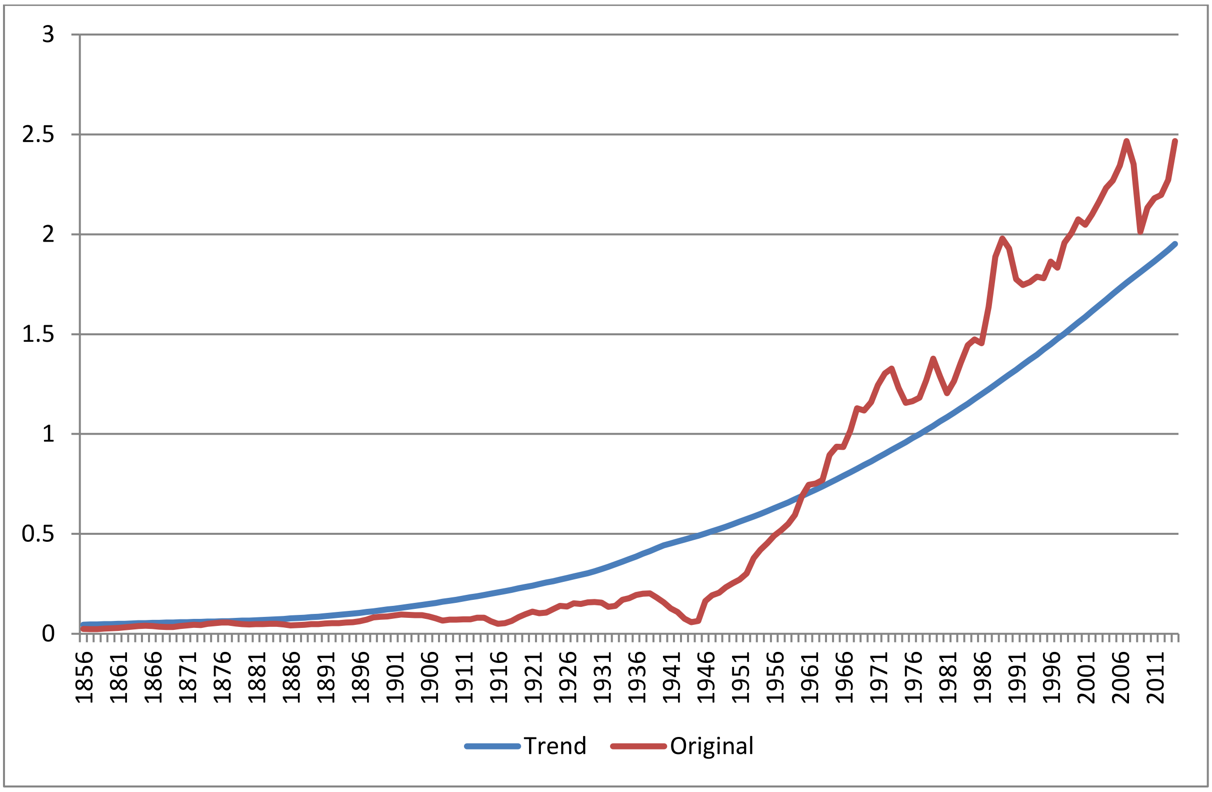


Source: Barro and Lee (2015) and MSSA analysis

Annex A3: Capital Investment

Data from the bank of England was used for the SSA Analysis and the results shown in Fig. A.3 which provides a similar time-series and long-term trend for capital investment in the UK. This chart shows that between 1888 to 1960 investment was below the long-term trend produced by Singular Spectral Analysis, with significantly higher if erratic, levels of investments from 1960 onwards. The SSA also shows that investment levels in 2014 returned to the level of investment in 2007. This is potentially significant, given that the current situation is above the long-term trend and so there potentially could be a reduction in the levels of investment to bring practice into line with trend.

Figure A.3: Investment Original Time-Series and Long-term Trend

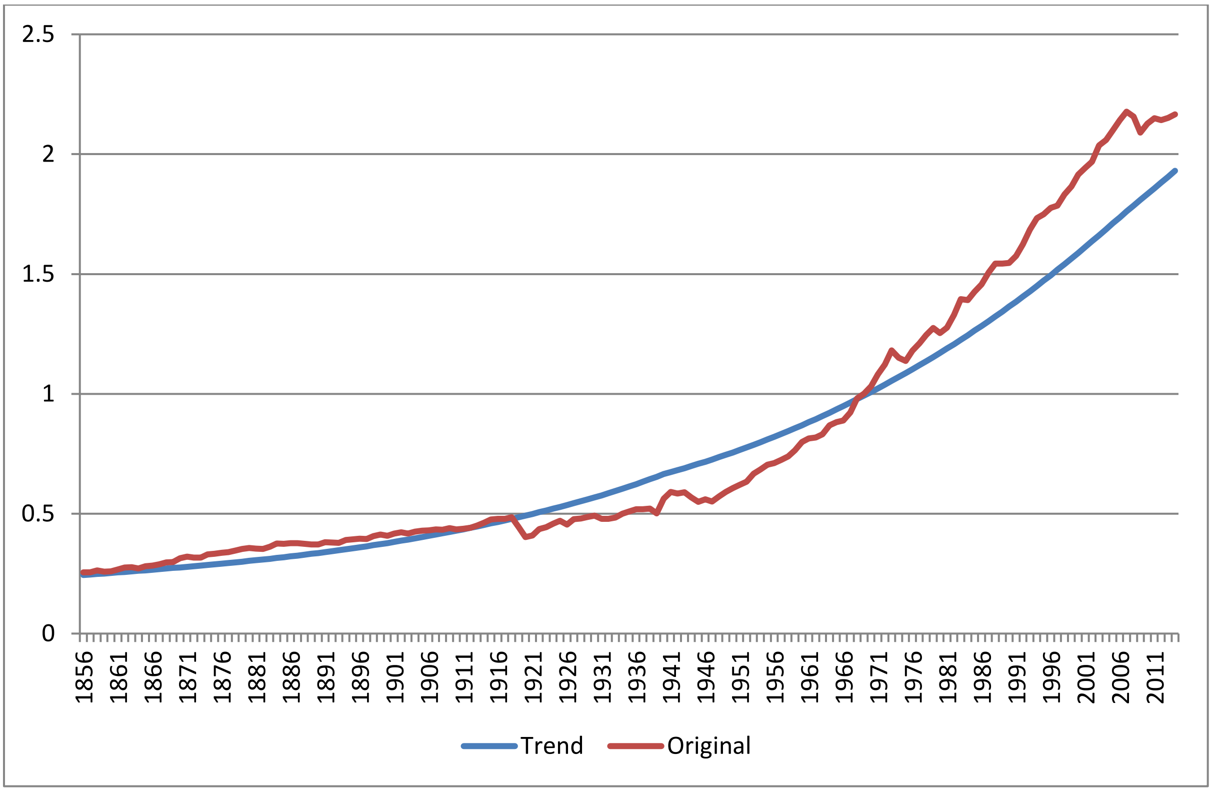


Source: Bank of England and MSSA analysis

Annex A4: Productivity

Figure A.4 provides an analysis of the whole economy productivity per capita data from the Bank of England data. This figure shows that productivity has shown the familiar exponential growth since 1856, with the period between 1917 and 1967 below the long-term trend. The period since 2006 shows the sustained impact of the recession with productivity, although recovering, still below the 2006 level. As with the investment analysis, as the current levels of productivity are above the long-term trend revealed by SSA, there is a possibility that in future productivity could decline to become consistent with the trend, leading to lower growth and output. This could mean less capacity for investment technologies, thus impeding the Transition.

Figure A.4: Productivity per capita original time series and long-term trend



Source: Bank of England and SSA Analysis

These single dimensional SSA analyses have been designed to be compared to the MSSA multi-dimensional analysis to compare the impact of the interaction between the variables.

Annex B1: Details of the High Nuclear Pathway

Table B1: DECC High Nuclear Pathway Details

Component	DECC model value	Commentary	Point capital cost 2015-2050
Nuclear power stations	2.7	26 3GW stations delivering ~1,540 TWh/yr	6,750
CCS power stations	1	Demonstration plants only	
CCS power station fuel mix	3	33% coal/biomass 66% gas/biomass after demo. plants	
Offshore wind	1.2	1,700 turbines in 2025	546
Onshore wind	1.4	5,300 turbines in 2025	1181
Wave	1	None in 2050	
Tidal Stream	1	None in 2050	
Tidal Range	1	None in 2050	
Biomass power stations	1	Only plants built and under construction (0.6 GW)	
Solar panels for electricity	1	No significant solar PV capacity installed	
Solar panels for hot water	1	As today, a negligible proportion of buildings with solar thermal	
Geothermal electricity	1	No deployment of geothermal energy	
Hydroelectric power stations	1	Supply of hydroelectricity maintained as current ~5 TWh/yr	
Small-scale wind	1	As today no discernible supply from micro-turbines	
Electricity imports	1	No electricity imports other than for balancing	
Land dedicated to bioenergy	4	17% of land used for energy crops	
Livestock and their management	2	Livestock numbers the same as today	
Volume of waste and recycling	2	Quantity of waste increase by 20%, increase in recycling	3766
Marine algae	3	Area same as all of the natural reserve used ~4 TWh/yr	
Type of fuels from biomass	3	Biomass mainly converted into liquid fuel	623
Bioenergy imports	3.7	260 TWh/yr of imported bioenergy in 2050	835
Domestic transport behaviour	2	Individuals travel 7% further, cars and vans 80% of 2050 miles	
Shift to zero emission transport	3	By 2050 32% plug-in hybrids, 48% zero emission, 22% buses electric	
Choice of fuel cells or batteries	2	By 2050 80% battery 20% hydrogen fuel cells	
Domestic freight	2	Some shift from road to rail and water and more efficient engines	

International aviation	2	By 2050 1305 increase in passengers 45% more fuel use	
International shipping	2	1/3 of technically feasible reductions emissions increase by 78%	
Average temperature of homes	2	Average room temperatures increase to 18oC	
Home insulation	3	Over 18m homes insulated, mean thermal leakage down 42%	312
Home heating electrification	3	Of new domestic heating systems 30%-60% use electricity	20,973
Home heating that is not electric	3	Dominant non-electric heat source is CHP	
Home lighting & appliances	2	Energy demand for domestic lights and appliances is stable	4,166
Electrification of home cooking	2	Energy use for cooking is entirely electric	
Growth in industry	2	UK industry goes in line with current trends	
Energy intensity of industry	1	No electrification of processes little improvement in intensity	
Commercial demand for heating and cooling	2	Space heating increases by 30%, water by 50%, cooling by 60%	18,291
Commercial heating electrification	3	Non-domestic heat 30%-60% from electricity	
Commercial heating that is not electric	3	Dominant non-electric heat source is CHP	
Commercial lighting & appliances	2	Energy demand for lights and appliances up by 15% cooking down 5%	
Electrification of commercial cooking	2	100% electric	
Grid reinforcement	3	7 GW storage with 2 more pumped storage, 15 GW interconnection & some demand shifting	1,663
Geosequestration	1	No geosequestation	
Storage, demand shifting & interconnection	2	4 GW storage and 10 GW inter connection for balancing	
Indigenous fossil-fuel production	1	Central case	

Source: Analysis of Pathway

Table B1.2: DECC High Nuclear Pathway Costs, Additional Costs and Job Years

	2014 Costs (£m)	2015-2050 Costs	2015 - 2050 Additional Costs (£m)	2015-2050 Additional Job Years*
Conventional thermal plant	£649	£37,625	£14,268	87,187
Combustion + CCS	£271	£1,868	-£7,904	-48,298
Nuclear power	£0	£197,397	£197,397	1,247,586
Onshore wind	£1,120	£27,401	-£12,923	-81,400
Offshore wind	£1,337	£51,473	£3,348	20,886
Hydroelectric	£13	£0	-£469	-2,880
Wave and Tidal	£0	£2,138	£2,138	13,567
Geothermal	£0	£0	£0	0
Distributed solar PV	£2	£0	-£64	-387
Distributed solar thermal	£0	£0	£0	0
Micro wind	£0	£0	£0	0
Biomatter to fuel conversion	£591	£37,729	£16,469	97,996
Bioenergy imports	£0	£0	£0	0
Agriculture and land use	£0	£0	£0	0
Agriculture and land use	£0	£0	£0	0
Energy from waste	£240	£16,371	£7,731	47,237
Waste arising	£2,657	£119,738	£24,081	147,917
Marine algae	£0	£0	£0	0
Electricity imports	£0	£0	£0	0
Electricity Exports	£0	£0	£0	0
Electricity grid distribution	£840	£56,448	£26,194	160,896
Storage, demand shifting, backup	£103	£10,325	£6,600	40,433
H2 Production	£10	£3,104	£2,728	16,754
Domestic heating	£6,717	£744,287	£502,477	3,942,765
Domestic insulation	£21,387	£774,297	£4,357	28,902
Commercial heating and cooling	£4,835	£278,583	£104,532	701,783
Domestic lighting, appliances, and cooking	£2,917	£125,769	£20,761	125,853
Commercial lighting, appliances, and catering	£40	£1,503	£72	435
Total	£43,730	£2,486,058	£911,793	6,547,233

Source: Analysis of Pathway

Annex B2: Friends of the Earth Pathway

Table B2: Friends of the Earth DECC 2050 Pathway

Component	DECC model value	Commentary	Point estimate of capital cost
Nuclear power stations	1	No new nuclear	
CCS power stations	1.7	204 TWh/yr from 20 to 35 CCS power stations	491
CCS power station fuel mix	4	100% gas and biomass	
Offshore wind	2.3	11,500 turbines in 2050	3,780
Onshore wind	2.3	9,200 turbines in 2050	970
Wave	4	~ 900 km of wave farms	2,419
Tidal Stream	4	10,600 tidal stream turbines	
Tidal Range	3	Eight tidal range schemes	
Biomass power stations	1	Only plants built and under construction (0.6GW)	
Solar panels for electricity	3.2	6.4m2 of photovoltaic panels per person	4,080
Solar panels for hot water	2	All suitable buildings get 30% of hot water from panels	2,769
Geothermal electricity	3	Supply grows quickly reaching 21 TWh/yr by 2030	356
Hydroelectric power stations	3.4	Supply grow very quickly 10.5 TWh/yr by 2035	
Small-scale wind	1	As today no discernible supply from micro-turbines	
Electricity imports	1	No electricity imports apart from balancing	477
Land dedicated to bioenergy	2	5% land used for energy crops	420
Livestock and their management	4	Livestock numbers decrease by 20%	
Volume of waste and recycling	4	Quantity of waste decreases by 20%	2639
Marine algae	1	No development of macro-algae cultivation	
Type of fuels from biomass	1	Biomass converted to a mixture of fuel types	49
Bioenergy imports	1	Imported biofuel declines from ~4 TWh/yr to zero	
Domestic transport behaviour	4	In 2050 same distance travelled but shift to public transport	
Shift to zero emission transport	4	By 2050 100% zero emissions vehicles all trains electric	
Choice of fuel cells or batteries	2	By 2050 80% battery 20% hydrogen fuel cells	
Domestic freight	4	Road modal share falls to 50% greater hybridization	
International aviation	4	By 2050 85% passengers increase 5% more fuel use	
International shipping	4	By 2050, emissions decrease by 46%	

Average temperature of homes	3	Average room temperatures decrease to 17oC	
Home insulation	4	Over 24m homes insulated, leakiness decreases by 50%	45
Home heating electrification	3	New domestic heating using electricity is 30%-60%	15,481
Home heating that is not electric	3	Dominant non-electric heat source is CHP	41
Home lighting & appliances	4	Energy demand for lights and appliances down by 60%	3,549
Electrification of home cooking	2	Energy used for domestic cooking is 100% electric	
Growth in industry	2	UK industry grows in line with current trends	
Energy intensity of industry	3	High electrification CCS captures 48% of emissions	
Commercial demand for heating and cooling	4	Heating demand down by 25% hot water by 10% cooling by 60%	
Commercial heating electrification	4	100% of non-domestic heat supplied by electricity	
Commercial heating that is not electric	3	Dominant non-electric heat source is CHP	
Commercial lighting & appliances	4	Energy demand for lights and appliances down by 30%, cooking by 25%	15,981
Electrification of commercial cooking	2	Commercial cooking 100% electric	
Geosequestration	4	CO2 sequestration rate ~110 million tonnes by 2050	1,921
Storage, demand shifting & interconnection	4	20 GW storage with large lagoons 30GW interconnection	4,256
Indigenous fossil-fuel production	1	Central case	

Source: Analysis of Pathway

Table B2.2: Friends of the Earth DECC 2050 Pathway Costs, Additional Costs and Job Years

	2014 Costs (£m)	2015-2050 Costs	2015 - 2050 Additional Costs (£m)	2015-2050 Additional Job Years
Conventional thermal plant	£842	£8,119	-£22,184	-135,553
Combustion + CCS	£288	£54,373	£43,994	268,821
Nuclear power	--	--	--	--
Onshore wind	£1,671	£61,604	£1,464	9,219
Offshore wind	£2,227	£242,433	£162,274	1,012,480
Hydroelectric	£53	£1,453	-£461	-2,831
Wave and Tidal	£103	£275,244	£271,522	1,722,588
Geothermal	--	--	--	--
Distributed solar PV	£151	£287,005	£281,562	1,706,817
Distributed solar thermal	£436	£90,279	£74,601	518,311
Micro wind	--	--	--	--
Biomatter to fuel conversion	£1,159	£21,868	-£19,868	-118,221
Bioenergy imports	--	--	--	--
Agriculture and land use	--	--	--	--
Agriculture and land use	--	--	--	--
Energy from waste	£247	£12,022	£3,136	19,165
Waste arising	£2,620	£104,408	£10,075	61,888
Marine algae	--	--	--	--
Electricity imports	--	--	--	--
Electricity Exports	--	--	--	--
Electricity grid distribution	£1,194	£159,063	£116,066	712,937
Storage, demand shifting, backup	£143	£21,344	£16,183	99,146
H2 Production	--	--	--	--
Domestic heating	£7,832	£472,058	£190,111	1,491,739
Domestic insulation	£658	£11,881	-£11,791	-78,205
Commercial heating and cooling	£9,658	£514,433	£166,733	1,119,370
Domestic lighting, appliances, and cooking	£2,934	£125,988	£20,348	123,347
Commercial lighting, appliances, and catering	--	--	--	--
Total	£32,217	£2,463,574	£1,303,765	8,531,020

Source: Analysis of Pathway

Annex B3: Details of the National Grid Pathway

Table B3: National Grid DECC 2050 Pathway

Component	DECC model value	Commentary	Point estimate of capital cost
Conventional Thermal plant			2129
Nuclear power stations	1.7	~11 3GW stations delivering ~240 TWh/yr	2305
CCS power stations	1.7	204 TWh/yr from 20 to 35 CCS power stations	1437
CCS power station fuel mix	2	66% coal/biomass 33% gas/biomass	
Offshore wind	1.6	~8,000 turbines in 2050 delivering ~150 TWh/yr	3542
Onshore wind	1.6	~6,400 turbines delivering ~40TWh/yr in 2050	819
Wave	1	None in 2050	395
Tidal Stream	2	1,000 tidal stream turbines	
Tidal Range	1	None in 2050	
Biomass power stations	1	Only plants currently built or under construction	
Solar panels for electricity	1.2	0.8 m2 photovoltaic panels per person	2837
Solar panels for hot water	1.9	~25% of suitable building get ~30% of their hot water from solar	4915
Geothermal electricity	1	No deployment of geothermal electricity generation	
Hydroelectric power stations	1.9	Supply grows slowly to ~6.5 TWh/yr in 2035	9
Small-scale wind	1	As today no discernible supply from micro-turbines	
Electricity imports	1	No electricity imports apart from balancing	
Land dedicated to bioenergy	3	10% of land used for energy crops	759
Livestock and their management	2	Livestock numbers the same as today	
Volume of waste and recycling	2	Quantity of waste increases by 20% increased recycling and EFW	3766
Marine algae	2	Area same as half natural reserve delivering ~4 TWh/yr	
Type of fuels from biomass	2	Biomass mainly converted to solid biofuel	623
Bioenergy imports	2	Up to 70 TWh/yr of imported bioenergy in 2050	
Domestic transport behaviour	3	Individuals travel 7% further than today, but more public transport	
Shift to zero emission transport	3	By 2050 32% plug-in hybrids, 48% zero emissions 22%buses electric	

Choice of fuel cells or batteries	1	By 2050 100% battery powered	
Domestic freight	3	Greater shift to rail and water, more efficient HGVs	
International aviation	2	By 2050 130% passenger increase 45% more fuel use	
International shipping	3	2/3 of feasible savings by 2050, emissions increase by 13%	
Average temperature of homes	2	Average room temperature increases to 18oC	
Home insulation	3	Over 18m homes insulated, thermal leakiness falls by 42%	312
Home heating electrification	4	New domestic heating using electricity is 80%-100%	20973
Home heating that is not electric	1	Dominant non-electric source of heating is gas or biogas	
Home lighting & appliances	2	Energy demand for lighting and appliances is stable	4166
Electrification of home cooking	1	Energy for domestic cooking remains 63% electric and 37% gas	
Growth in industry	2	Industry grows in line with current trends	
Energy intensity of industry	2	Some processes electrified, moderate improvements in emissions	
Commercial demand for heating and cooling	3	Space heating demand stable, hot water demand increases by 25%	
Commercial heating electrification	4	80%-100% of non-domestic heat supplied by electricity	18291
Commercial heating that is not electric	4	Mixture of gas/biogas and CHP	
Commercial lighting & appliances	3	Electrical demand from lights and appliances decreases by 20%	
Electrification of commercial cooking	2	100% electric	
Geosequestration	1	No Geosequestation	
Storage, demand shifting & interconnection	2	4 GW storage and 10 GW interconnection	2633
Indigenous fossil-fuel production	1	Central case	

Source: Analysis of Pathway

Table B3.2: National Grid DECC 2050 Pathway Costs, Additional Costs and Job Years

	2014 Costs (£m)	2015-2050 Capital Costs	2015 - 2050 Additional Costs (£m)	2015-2050 Additional Job Years *
Conventional thermal plant	£483	£35,866	£18,491	112,988
Combustion + CCS	£282	£35,813	£25,653	156,749
Nuclear power	--	£73,148	£73,148	462,312
Onshore wind	£1,246	£35,719	-£9,154	-57,657
Offshore wind	£1,844	£127,641	£61,245	382,127
Hydroelectric	£29	£395	-£654	-4,019
Wave and Tidal	--	£7,820	£7,820	49,614
Geothermal	--	--	--	--
Distributed solar PV	£7	£26,297	£26,049	157,905
Distributed solar thermal	£392	£81,251	£67,140	466,480
Micro wind	--	--	--	--
Biomatter to fuel conversion	£1,686	£33,623	-£27,084	-161,159
Bioenergy imports	--	--	--	--
Agriculture and land use	--	--	--	--
Agriculture and land use	--	--	--	--
Energy from waste	£240	£16,371	£7,731	47,237
Waste arising	£2,657	£119,738	£24,081	147,917
Marine algae	--	--	--	--
Electricity imports	--	--	--	--
Electricity Exports	--	--	--	--
Electricity grid distribution	£870	£73,862	£42,526	261,217
Storage, demand shifting, backup	£118	£18,298	£14,037	85,999
H2 Production	--	--	--	--
Domestic heating	£6,863	£677,341	£430,270	3,376,182
Domestic insulation	£21,387	£774,297	£4,357	28,902
Commercial heating and cooling	£3,547	£180,182	£52,491	352,400
Domestic lighting, appliances, and cooking	£2,934	£125,988	£20,348	123,347
Commercial lighting, appliances, and catering	£252	£8,585	-£488	-2,958
Total	£44,840	£2,452,237	£838,007	5,985,584

Source: Analysis of Pathway

Annex B4: Details of the MARKAL 3.26 Least Cost Pathway

Table B4: MARKAL 3.26 Least Cost DECC 2050 Pathway

Component	DECC model value	Commentary	Point estimate of capital cost
Thermal Power	1.8		2,129
Nuclear power stations	1.8	11 3GW power stations delivering ~250 TWh/yr	2,634
CCS power stations	1.6	190 TWh/yr from 20 - 32 CCS power stations	1,232
CCS power station fuel mix	2	66% coal/biomass 33% gas/biomass CCS	
Offshore wind	1.3	1,900 offshore turbines by 2025	1,771
Onshore wind	1.3	5,700 onshore turbines by 2025	410
Wave	2	~300km of wave farms	2,296
Tidal Stream	2.5	1,300 tidal stream turbines	
Tidal Range	2.5	Three tidal range schemes	
Biomass power stations	1	Only plants built and under construction	
Solar panels for electricity	1	No significant solar PV installed	
Solar panels for hot water	2	~30% of suitable buildings get ~30% hot water	5,462
Geothermal electricity	1	No deployment of geothermal electricity	
Hydroelectric power stations	1.5	6 TWh/yr hydro-electricity by 2050	5
Small-scale wind	1	As today no discernible micro wind turbines	
Electricity imports	1.8	27 TWh/y of electricity imports	
Land dedicated to bioenergy	3	10% of land used for energy crops	968
Livestock and their management	2	Livestock numbers the same as today	
Volume of waste and recycling	2	Waste increases by 2%, increase in recycling & EFW	3,765
Marine algae	1	No development of macro-algae cultivation	
Type of fuels from biomass	1	Imported biofuels decline from ~4 TWh/yr to zero	
Bioenergy imports	2.5	88 TWh/yr of imported bioenergy by 2050	623
Domestic transport behaviour	4	In 2050, people travel the same with a shift to public transport	
Shift to zero emission transport	3	By 2050 32% plug-in hybrids 48% zero emission vehicles	
Choice of fuel cells or batteries	1	By 2050 100% battery powered	
Domestic freight	4	Road share drops to 50%, greater hybridization and rail	

International aviation	1	130% increase in passengers, 50% more fuel used	
International shipping	1	No improvements from efficiency emissions up 139%	
Average temperature of homes	4	Average room temperatures fall to 16oC	
Home insulation	3	Over 18m homes insulated leakiness down by 42%	312
Home heating electrification	3	New domestic heating 30%-60% electric	2,0973
Home heating that is not electric	3	Dominant non-electric heat source is CHP	59
Home lighting & appliances	4	Energy demand from lighting and appliances down by 60%	
Electrification of home cooking	2	All domestic cooking electrical	
Growth in industry	2	Some processes electrified, moderate improvements in emissions	
Energy intensity of industry	3	High electrification CCS captures 48% of emissions	
Commercial demand for heating and cooling	4	Heating demand down by 25% hot water by 10% cooling by 60%	
Commercial heating electrification	3	Non-domestic heat 30-60% electric	18,291
Commercial heating that is not electric	2	Dominant non-electric heat source is CHP	
Commercial lighting & appliances	4	Energy demand for lights and appliances down by 30%, cooking by 25%	
Electrification of commercial cooking	2	100% electric	
Geosequestration	1	No geosequestation	
Storage, demand shifting & interconnection	2	4 GW storage and 10 GW interconnection for balancing	2,660
Indigenous fossil-fuel production	1	Central case	

Source: Analysis of Pathway

Table B4.2: MARKAL 3.26 DECC 2050 Pathway Costs, Additional Costs and Job Years

	2014 Costs (£m)	2015-2050 Capital Costs	2015 - 2050 Additional Costs (£m)	2015-2050 Additional Job Years*
Conventional thermal plant	£482	£22,679	£5,321	32,516
Combustion + CCS	£281	£30,959	£20,854	127,428
Nuclear power	£0	£83,598	£83,598	528,357
Onshore wind	£1,057	£23,242	-£14,808	-93,271
Offshore wind	£1,464	£70,515	£17,822	111,197
Hydroelectric	£22	£211	-£581	-3,566
Wave and Tidal	-£35	£84,711	£85,987	545,516
Geothermal	£0	£0	£0	0
Distributed solar PV	£2	-£3	-£66	-403
Distributed solar thermal	£436	£90,279	£74,601	518,311
Micro wind	£0	£0	£0	0
Biomatter to fuel conversion	£1,806	£43,112	-£21,904	-130,337
Bioenergy imports	£0	£0	£0	0
Agriculture and land use	£0	£0	£0	0
Agriculture and land use	£0	£0	£0	0
Energy from waste	£240	£16,371	£7,731	47,237
Waste arising	£2,657	£119,738	£24,081	147,917
Marine algae	£0	£0	£0	0
Electricity imports	£0	£0	£0	0
Electricity Exports	£0	£0	£0	0
Electricity grid distribution	£769	£56,239	£28,549	175,363
Storage, demand shifting, backup	£108	£11,782	£7,909	48,455
H2 Production	£0	£0	£0	0
Domestic heating	£5,785	£610,613	£402,367	3,157,236
Domestic insulation	£21,387	£774,297	£4,357	28,902
Commercial heating and cooling	£2,677	£103,140	£6,783	45,537
Domestic lighting, appliances, and cooking	£2,917	£125,769	£20,761	125,853
Commercial lighting, appliances, and catering	£462	£14,552	-£2,080	-12,608
Total	£42,515	£2,281,806	£751,281	5,399,636

Source: Analysis of Pathway

Annex C: Detailed Occupations by Construction Subsector

Pathways, Technologies and Construction Subsectors

Each pathway consists of a bundle of technologies at various scales with many technologies appearing in all the pathways with different emphases. Each technology is briefly described and then the construction subsectors associated with their construction or installation are listed.

The subsectors of construction activity are based on aggregates of four-digit Standard Industrial Classification (SIC 2007) categories within the construction sector. These are:

A) Construction of domestic and non-domestic buildings –

- SIC 41.20: Construction of buildings

B) Construction of roads and railways –

- SIC 42.11: Construction of roads and motorways
- SIC 42.12: Construction of railways and underground railways
- SIC 42.13: Construction of bridges and tunnels

C) Other civil engineering

- SIC 42.21: Construction of utility projects for fluids
- SIC 42.22: Construction of utility projects for electricity and telecommunications
- SIC 42.91: Construction of water projects
- SIC 42.99: Construction of other civil engineering projects n.e.c.

D) Specialised construction activities

- SIC 43.11: Demolition
- SIC 43.12: Site preparation
- SIC 43.13: Test drilling and boring

E) Electrical installation

- SIC 43.21: Electrical installation

F) Plumbing heating and heat-pumps

- SIC 43.22: Plumbing, heat and air-conditioning installation

G) Building completion and fitting out

- SIC 43.29: Other construction installation
- SIC 43.31: Plastering
- SIC 43.32: Joinery installation
- SIC 43.33: Floor and wall covering
- SIC 43.34: Painting and glazing
- SIC 43.39: Other building completion and finishing
- SIC 43.91: Roofing activities
- SIC 43.99: Other specialised construction activities n.e.c

Basic Descriptions of Technologies and Subsector Analysis

Awkwardly, the scale and bundle information uses different descriptions of the technologies than the cost data. Here the information has been standardised onto the descriptions used in the scale and bundle documentation

Conventional thermal plant – Mainly powered by gas or biomatter - 10% Construction of buildings and 90% Civil Engineering

CCS power stations – 10% Construction of buildings and 90% Civil Engineering

Nuclear power – 10% Construction of buildings, 50% Civil Engineering and 40% Specialised construction activities

Onshore wind – 10% Construction of roads and railways, 60% Other civil engineering, 20% Specialised construction activities and 10% Electrical installation

Offshore wind – 70% Civil engineering, 20% Specialised construction activities and 10% Electrical installation

Hydroelectric – Mainly small scale as large sites already exploited – 100% Civil engineering

Wave and Tidal – Still largely experimental with the final mix down to the designs used- 50% civil engineering 40% Specialised construction activities and 10% Electrical installation

Geothermal – 100% Other civil engineering

Distributed solar PV – a combination of domestic installations and large scale solar farms - 100% Electrical installation

Distributed solar thermal – largely domestic installations - 100% Plumbing heating & heat-pumps

Micro wind – not included in any of the pathways as probably does not create scalable solutions - 100% Electrical installation

Biomatter to fuel conversion – focus on the capital structures required the building and equipment used to store and process biomatter – 60% Building construction and 40% Other civil engineering

Bioenergy imports – focus on the structures needed to enable imports – 100% Building construction

Agriculture and land use – Not included in analysis

Energy from waste – 10% Road and Railway construction and 90% Other civil engineering

Waste arising – processing of refuse and sewage – 100% Other civil engineering

Marine algae – Structures associated with growth and processing of algae – 50% Building construction and 50% Other civil engineering

Electricity imports – Grid extensions and HVDC converters – 100% Other civil engineering

Electricity Exports – Grid extensions and HVDC converters – 100% Other civil engineering

Electricity grid distribution – Grid extensions and reinforcement – 100% Other civil engineering

Storage, demand shifting, backup – Pumped storage, batteries and equipment modifications – 80% Other civil engineering and 20% Electrical installations

H2 Production – Not used a great deal in the selected pathways – 100% Other civil engineering

Domestic heating – replacement of gas fired systems with electrical systems mainly heat pumps – 10% Building construction, 10% Specialised construction, 30% Electrical installation and 50% Plumbing heating and heat pumps

Domestic insulation – Installation of roof, cavity wall and external cladding insulation – 50% Building construction and 50% Building completion and fitting out

Commercial heating and cooling – Mainly the installations of ground and air source heat pumps – 20% Other Specialised construction activities, 10% Electrical installation and 70% Plumbing heating and heat-pumps

Domestic lighting, appliances, and cooking – Improvement of energy efficiency of domestic appliances – 100% Electrical installation

Commercial lighting, appliances, and catering - Improvement of energy efficiency of commercial appliances 100% Electrical installations

Table C2: Detailed Occupations by Construction Subsector, 2015

	Specialised Construction Activities	Electrical Installation	Plumbing Heating & heat-pumps	Building completion & fitting out
Production managers in manufacturing	**	6300	5900	**
		3.0%	2.9%	
Production managers in construction	5100	6700	**	15800
	3.4%	3.2%		3.0%
Financial Managers and Directors	**	**	**	**
Marketing and Sales Directors	**	**	**	**
Property and Housing Managers	**	**	**	**
Other Managers and Directors	7700	9500	9600	18400
	5.1%	4.5%	4.7%	3.5%
Civil Engineers	**	**	**	**
Quantity Surveyors	**	**	**	**
Construction Project Managers	**	**	**	**
Other Professional Occupations	8100	19500	13600	10700
	5.3%	9.3%	6.6%	2.0%
Architectural Technicians	**	**	**	**
Housing Officers	**	**	**	**
Estimator and Valuers	**	**	**	**
Sales Account Managers	**	**	**	4164
				.8%
Other Associate Professional and Technical	**	9000	6700	7900
		4.3%	3.2%	1.5%
Bookkeepers and Payroll Managers	**	**	**	**
Other Administrative Occupations	4800	5200	5500	9800
	3.1%	2.5%	2.7%	1.9%
Office Managers	**	**	**	**
Personal Assistants	**	**	**	4700
				.9%

Other Admin and Secretarial	6200	9900	8900	10800
	4.0%	4.7%	4.3%	2.1%
Metal Working Production Fitters	**	**	**	4636
				.9%
Air Conditioning and Refrigeration	**	**	12214	**
			6.0%	
Electricians and Electrical Fitters	**	100192	**	4177
		47.6%		.8%
Telecommunication Engineers	**	13792	**	**
		6.5%		
Electrical and Electronic Trade nec	**	8261	**	**
		3.9%		
Bricklayers and Masons	21630	**	**	5441
	14.2%			1.0%
Roofers Roof Tilers and Slaters	**	**	**	32063
				6.1%
Plumbers and Heating and Ventilation	**	**	117544	5334
			57.3%	1.0%
Carpenters and Joiners	26785	**	**	103043
	17.5%			19.7%
Glaziers and Window Fabricators	**	**	**	18200
				3.5%
Construction and Building Trades nec	**	**	**	66254
				12.7%
Plasterers	**	**	**	30585
				5.9%
Floorers and Wall Tilers	**	**	**	33821
				6.5%
Painters and Decorators	**	**	**	70397
				13.5%
Construction and Building Supervisors'	**	**	**	**
Other Skilled Trades Occupations	16740	8543	14619	13405
	11.0%	4.1%	7.1%	2.6%
Other Caring leisure and Service Occupations	**	**	**	**
Other Sales and Customer Service	**	**	**	5106
				1.0%
Scaffolders and Stagers	19737	**	**	**
	12.9%			
Road Construction Operatives	**	**	**	**
Construction Operatives nec	4049	**	**	14390
	2.7%			2.8%
	8922	**	**	**

Mobile Machine Drivers	5.8%			
Other Process Plant and Operatives	9294	**	**	5772
	6.1%			1.1%
Elementary Construction Operatives	7915	**	**	17841
	5.2%			3.4%
Other Elementary Occupations	**	8063	5031	8803
		3.8%	2.5%	1.7%
Total	152760	210585	205147	522375
	100.0%	100.0%	100.0%	100.0%

Source: Analysis of Annual 2015 Labour Force Survey
*Notes ** values suppressed as below reportable level, included in subtotals and totals, other values rounded to the nearest 100*

Table C2: Detailed Occupations by Construction Subsector (continued), 2015

	Construction of Buildings	Construction of Roads & Railways	Other Civil Engineering	Total
Production managers in manufacturing	**	**	4200	25246
			2.2%	1.2%
Production managers in construction	76755	5600	13200	126970
	10.5%	4.5%	6.9%	5.9%
Financial Managers and Directors	7200	**	**	18621
	1.0%			0.9%
Marketing and Sales Directors	4000	**	**	8553
	0.6%			0.4%
Property and Housing Managers	6100	**	**	8122
	0.8%			0.4%
Other Managers and Directors	11800	5800	9600	41796
	1.6%	4.7%	5.0%	2.0%
Civil Engineers	**	5088	18555	30587
		4.1%	9.7%	1.4%
Quantity Surveyors	15361	**	4172	26179
	2.1%		2.2%	1.2%
Construction Project Managers	24939	**	4650	38881
	3.4%		2.4%	1.8%
Other Professional Occupations	23634	10927	26559	90164
	3.2%	8.9%	13.9%	4.2%

Architectural Technicians	4299	**	**	4959
	.6%			.2%
Housing Officers	6725	**	**	6725
	.9%			.3%
Estimator and Valuers	4804	**	**	9466
	.7%			.4%
Sales Account Managers	5013	**	**	18860
	.7%			.9%
Other Associate Professional and Technical	27932	15599	22203	78851
	3.8%	12.7%	11.6%	3.7%
Bookkeepers and Payroll Managers	10675	**	**	26962
	1.5%			1.3%
Other Administrative Occupations	13250	**	**	42312
	1.8%			2.0%
Office Managers	4420	**	**	13625
	.6%			.6%
Personal Assistants	7508	**	**	20203
	1.0%			.9%
Other Admin and Secretarial	16874	7753	14601	37683
	2.3%	6.3%	7.6%	1.8%
Metal Working Production Fitters	6446	**	**	20679
	.9%			1.0%
Air Conditioning and Refrigeration	**	**	**	12214
				.6%
Electricians and Electrical Fitters	19756	**	**	132933
	2.7%			6.2%
Telecommunication Engineers	**	**	**	15321
				.7%
Electrical and Electronic Trades nec	**	**	**	13940
				.7%
Bricklayers and Masons	38190	**	**	65929
	5.2%			3.1%
Roofers Roof Tilers and Slaters	6546	**	**	38718
	.9%			1.8%
Plumbers and Heating and Ventilation	11198	**	**	135751
	1.5%			6.3%
Carpenters and Joiners	66854	**	**	201012
	9.1%			9.4%
Glaziers and Window Fabricators	3054	**	**	21254
	.4%			1.0%
Construction and Building Trades nec	119367	**	4275	197877
	16.3%		2.2%	9.3%

Plasterers	14192	**	**	45515
	1.9%			2.1%
Floorers and Wall Tilers	1005	**	**	35996
	.1%			1.7%
Painters and Decorators	12721	**	**	83935
	1.7%			3.9%
Construction and Building Supervisors'	19750	**	8213	39855
	2.7%		4.3%	1.9%
Other Skilled Trades Occupations	15300	15904	23095	53866
	2.1%	12.9%	12.1%	2.5%
Other Caring leisure and Service Occupations	**	**	**	3669
				.2%
Other Sales and Customer Service	4255	**	**	16371
	.6%			.8%
Scaffolders and Stagers	4410	**	**	25058
	.6%			1.2%
Road Construction Operatives	983	14094	**	17403
	.1%	11.4%		.8%
Construction Operatives nec	17146	4335	4367	45215
	2.3%	3.5%	2.3%	2.1%
Mobile Machine Drivers	6149	5704	6315	27754
	.8%	4.6%	3.3%	1.3%
Other Process and Plant Operatives	11130	7071	8083	42225
	1.5%	5.7%	4.2%	2.0%
Elementary Construction Operatives	76918	22002	8450	140227
	10.5%	17.9%	4.4%	6.6%
Other Elementary Occupations	7527	**	**	30563
	1.0%			1.4%
Total	732661	123127	191390	2138045
	100.0%	100.0%	100.0%	100.0%

Source: Analysis of Annual 2015 Labour Force Survey
*Notes ** values suppressed as below reportable level, included in subtotals and totals, other values rounded to the nearest 100*

Annex D: Long Qualifications

Table D1: Top five percent of Construction Qualifications at Levels 3 and 4

Qualification Title	Owner Organisation Name	Level2	Maximum Guided Learning Hours	Minimum Guided Learning Hours
Cskills Awards Level 2 NVQ Diploma in Post Tensioning Operations (Construction) (QCF)	Cskills Awards	3	733	500
Pearson Edexcel Level 2 NVQ Diploma in Post Tensioning Operations (Construction) (QCF)	Pearson Education Ltd	3	733	500
Cskills Awards Level 2 NVQ Diploma in Construction Plant or Machinery Maintenance (Construction) (QCF)	Cskills Awards	3	735	641
IMI Level 2 NVQ Diploma in Construction Plant or Machinery Maintenance (Construction)	The Institute of the Motor Industry	3	735	641
NOCN Level 2 NVQ Diploma in Construction Plant or Machinery Maintenance (Construction) (QCF)	NOCN	3	735	641
City & Guilds Level 2 Extended Diploma In Bench Joinery (QCF)	City and Guilds of London Institute	3	733	733
City & Guilds Level 2 NVQ Diploma in Planned and Reactive Maintenance on Heating and Ventilating Equipment (QCF)	City and Guilds of London Institute	3	733	733
Cskills Awards Level 2 Diploma in Steeplejacking (Construction) (QCF)	Cskills Awards	3	735	735
Cskills Awards Level 2 Diploma in Bench Joinery (Construction)	Cskills Awards	3	736	736
City & Guilds Level 2 Extended Diploma In Site Carpentry (QCF)	City and Guilds of London Institute	3	750	750
Cskills Awards Level 2 Diploma in Lightning Conductor Engineering (Construction) (QCF)	Cskills Awards	3	750	750
CSkills Awards Level 2 Diploma in Roof Sheeting and Cladding (QCF)	Cskills Awards	3	750	750
Cskills Awards Level 2 Diploma in Formworking (QCF)	Cskills Awards	3	751	751
NOCN Level 2 Diploma in Formworking (QCF)	NOCN	3	751	751

City & Guilds Level 2 Extended Diploma in Wall and Floor Tiling (QCF)	City and Guilds of London Institute	3	757	757
City & Guilds Level 2 Extended Diploma In Bricklaying (QCF)	City and Guilds of London Institute	3	760	760
City & Guilds Level 2 Extended Diploma in Painting and Decorating (QCF)	City and Guilds of London Institute	3	777	777
Cskills Awards Level 2 Diploma in Plastering (Construction)	Cskills Awards	3	789	789
CSkills Awards Level 2 Diploma in Built-up Felt Roofing (QCF)	Cskills Awards	3	810	810
Cskills Awards Level 2 Diploma in Craft Masonry (Construction) (QCF)	Cskills Awards	3	821	821
NOCN Level 2 Diploma in Steelfixing Occupations (Construction) (QCF)	NOCN	3	846	846
City & Guilds Level 2 Extended Diploma In Plastering (QCF)	City and Guilds of London Institute	3	862	858
Cskills Awards Level 2 Diploma in Construction Plant or Machinery Maintenance (Construction) (QCF)	Cskills Awards	3	894	894
IMI Level 2 Diploma in Construction Plant or Machinery Maintenance (Construction) (VRQ)	The Institute of the Motor Industry	3	894	894
NOCN Level 2 Diploma in Construction Plant or Machinery Maintenance (Construction) (QCF)	NOCN	3	894	894
Pearson BTEC Level 3 Diploma in Construction Occupations (QCF)	Pearson Education Ltd	4	1600	1410
City & Guilds Level 3 Diploma in Gas Utilisation Installation: Water Heating and Wet Central Heating (QCF)	City and Guilds of London Institute	4	1451	1451
EAL Level 3 Diploma in Gas Utilisation Installation: Water Heating and Wet Central Heating (QCF)	Excellence, Achievement & Learning Limited	4	1451	1451
EAL Level 3 Diploma in Gas Utilisation Installation: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating and Wet Central Heating (QCF)	Excellence, Achievement & Learning Limited	4	1491	1491
City & Guilds Level 3 Diploma in Gas Utilisation Installation and	City and Guilds of	4	1526	1526

Maintenance: Water Heating and Wet Central Heating (QCF)	London Institute			
EAL Level 3 Diploma in Gas Utilisation Installation and Maintenance: Water Heating and Wet Central Heating (QCF)	Excellence, Achievement & Learning Limited	4	1526	1526
City & Guilds Level 3 Diploma in Gas Utilisation Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating and Wet Central Heating (QCF)	City and Guilds of London Institute	4	1534	1534
EAL Level 3 Diploma in Gas Utilisation Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating and Wet Central Heating (QCF)	Excellence, Achievement & Learning Limited	4	1534	1534
City & Guilds Level 3 Diploma in Gas Utilisation Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating, Limited Wet Central Heating and Domestic Warm Air (QCF)	City and Guilds of London Institute	4	1580	1580
EAL Level 3 Diploma in Gas Utilisation Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating, Limited Wet Central Heating and Domestic Warm Air (QCF)	Excellence, Achievement & Learning Limited	4	1580	1580
City & Guilds Level 3 Diploma in Gas Utilisation Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating, Wet Central Heating and Domestic Warm Air (QCF)	City and Guilds of London Institute	4	1588	1588
EAL Level 3 Diploma in Gas Utilisation Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating, Wet Central Heating and Domestic Warm Air (QCF)	Excellence, Achievement & Learning Limited	4	1588	1588
City & Guilds Level 3 Diploma in Gas Utilisation Installation: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating and Wet Central Heating (QCF)	City and Guilds of London Institute	4	1593	1593
City & Guilds Level 3 Diploma in Gas Utilisation Installation: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating, Wet Central Heating and Domestic Warm Air (QCF)	City and Guilds of London Institute	4	1647	1647

EAL Level 3 Diploma In Gas Utilisation Installation: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating, Wet Central Heating and Domestic Warm Air (QCF)	Excellence, Achievement & Learning Limited	4	1647	1647
City & Guilds Level 3 Diploma in Gas Utilisation Installation and Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating and Wet Central Heating (QCF)	City and Guilds of London Institute	4	1810	1810
EAL Level 3 Diploma In Gas Utilisation Installation and Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating and Wet Central Heating (QCF)	Excellence, Achievement & Learning Limited	4	1810	1810
City & Guilds Level 3 Diploma in Gas Utilisation Installation and Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating, Wet Central Heating and Domestic Warm Air (QCF)	City and Guilds of London Institute	4	1918	1918
EAL Level 3 Diploma in Gas Utilisation Installation and Maintenance: Cookers, Tumble Dryers, Leisure, Domestic Space Heating, Water Heating and Wet Central Heating and Domestic Warm Air (QCF)	Excellence, Achievement & Learning Limited	4	1918	1918

Source: Analysis of Ofqual Register