

**AN ANALYSIS OF THE SOCIOTECHNICAL TRANSITION  
PROCESS FROM THE EXISTING CENTRALISED  
ALTERNATING CURRENT VOLTAGE ELECTRICAL  
SYSTEM IN THE UK TO ONE WHERE DISTRIBUTED  
DIRECT CURRENT VOLTAGE IS USED TO MEET THE  
ENERGY NEEDS OF THE BUILT ENVIRONMENT**

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## List of Abbreviations

AC	Alternating Current
CCS	Carbon capture and storage
CHP	Combined Heat and Power (systems)
CoP	Code of Practice
DC	Direct Current
DECC	Department for Energy and Climate Change
DEFRA	Department for Environment, Food & Rural Affairs
DNOs	Distribution Network Operators
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DTI	the Department of Trade & Industry
EJ/yr	Exajoule (of energy) per year
EPSRC	Engineering and Physical Sciences Research Council
ESCos	Energy Service Companies
FITs	Feed-in Tariffs
GEA	Global Energy Assessment (report)
GEC	Global Energy Challenges
GIB	Green Investment Bank
GSM	Global System for Mobile Communication
HVDC	High Voltage Direct Current
IEEE	Institute of Electrical and Electronic Engineers
IET	The Institute of Engineering and Technology
IPCC	The Intergovernmental Panel on Climate Change
IoT	Internet of Things
LED	Light Emitting Diode
MLP	Multi-Level Perspective
MP	Member of Parliament
NIA	Network Innovation Allowance (type of funding)
NIC	Network Innovation Competition (type of funding)
<i>Ofgem</i>	The Office of Gas and Electricity Markets
PoE	Power over Ethernet
PVs	Photovoltaics (solar panels)
RCUK	Research Councils UK
SCADA	Supervisory Control and Data Acquisition systems
TTs	Technical Transitions
TWh	Tera Watt hours
UK	United Kingdom
UPS	Universal Power Supply
USB	Universal Serial Bus
V	Volts
VoiP	Voice over Internet Protocol
W	Watts

## Definitions

**Alternating current voltage:** is electricity that has a fluctuating current output. In this thesis the usage of capitals for 'AC', describes the sociotechnical alternating current electricity system, which is more than just the technical aspect of the system, which by itself could be denoted by the lower case 'ac'.

**Boundary points:** are points of interaction between two systems, two social networks or two institutions

**Boundary spanners:** these are the people who function in the space between two systems, bridging the gap between the systems or networks.

**Built environment:** this includes all types of buildings, from beach huts, to houses and blocks of flats, to offices and industrial buildings.

**Direct current voltage:** is electricity that has a constant current output. In this thesis the usage of capitals for 'DC', describes the sociotechnical direct current electricity system, which is more than just the technical aspect of the system, which by itself could be denoted by the lower case 'dc'.

**Distributed energy generation:** this research defined distributed generation as a system where the generating system, for example solar panels, is located at the point of demand, i.e. on the building that consumes the energy. Such systems can be stand-alone, i.e. not connected to another supply grid or connected to a national grid.

**Energy independence:** is defined within this thesis as - the ability of a nation or a person to have the energy needed to be able to live a normal accustomed lifestyle without being dependent on another nation or person to provide this energy

**Energy security:** is defined within this thesis as, the ability of a nation or a person to procure the raw materials and technology to generate enough energy to be able to keep themselves in their accustomed lifestyle

**Extra low voltage:** a DC voltage below 100 Volts DC or 120 V AC

**Institution:** any entity that has rules and a framework which governs its functionality

**Institutional structuration:** the mechanism whereby actions can take place within the structures of an institution.

**Window of opportunity:** this research defines a window of opportunity as being the time period between when a disruptive change in the landscape occurs, until the problem is solved. For technological transitions within the energy system, that are trying to deal with problems that humanity faces, the window can be said to be open for decades.

## Abstract

This study concerns the potential sociotechnical transition of the current UK centralised alternating current (AC) electricity system to one where distributed direct current (DC) systems may proliferate. The development of the new distributed DC system has the potential to address a number of global challenges including the UN's 17 Sustainability Challenges, particularly in terms of city and disaster resilience, energy security and energy independence. With the development of renewables and small-scale storage, among other technologies, this transition becomes a technical possibility. As transitions theory identifies energy systems as sociotechnical, transitions are a complex and people-centred process, an issue that has been identified that creates barriers to technical transitions. The multi-level perspective (MLP) is used as the theoretical framework and its applicability for future transitions is considered.

The research proposes a “bottom-up” approach, focused on the demand side within the built environment, to avoid the transition developing into a wicked problem. Using a mixture of primary interview data, analysed using thematic analysis, supported by data, from published academic and industry/governmental literature, a multi-method case study approach is used to develop a transitions model between the “as is” state and the potential future state with DC systems. Also identified were the institutions within the social and technical networks of the electricity regime, barriers and enablers to the transition, boundary points between the networks and the structurations of institutions within these networks.

Key findings are a lack of interdisciplinary thinking among different academic disciplines, a lack of DC standards and home appliances, and that DC is in focus for the office rather than the home. Knowledge dissemination especially via education, government procurement and energy policy, and the importance of independence from the market are key components for a successful proliferation. A conundrum connecting renewable generation, the carbon debate and energy policy, is identified. With a deeper understanding of the regime, landscape and with a multi-systems approach, a tentative solution is provided.

Contributions to knowledge are: the transitions model; the sociotechnical characterisation of the electricity system; a better understanding of how liability, living standards, disaster risk reduction and city resilience can be impacted by failure chains associated with power cuts; and a deeper understanding of the MLP model.



# Chapter 1

## Framing the Research

### 1.1. Introduction

This research investigates a theoretical future transition within the field of sustainable energy transitions. It uses the UK's electricity system as a case study to investigate a sociotechnical transition. Transforming the UK's electricity system from a centralised alternating current voltage (AC) system to one where distributed direct current (DC) voltage systems proliferate, is a market transformation project. For change to occur, a sequence or chain of smaller transitions will have to take place. In order to find a possible blueprint for the transition, interim transitions are identified and combined into a single transition framework. The question is '*if it isn't broken why fix it*'? This research identifies global challenges that could possibly be alleviated through the use of distributed direct current electricity systems. Due to the cross-disciplinarity of the research, the social sciences, political science, socioeconomics and engineering have been brought together in an attempt to give a global answer to the research question.

### 1.2. The research question, aims and objectives

The main research question is: if the UK is to move to an electrical system that includes the many advantages that direct current voltage systems can provide, how would the transition be accomplished?

To answer this question two aims have to be achieved:

1. The first aim is to establish the sociotechnical nature of the distributed DC voltage system
2. The second aim is to identify a transition pathway that would take the UK from a country whose electricity system is centralised AC, to one where distributed DC systems are proliferate

In order to reach these aims the following objectives will need to be achieved:

1. Characterising the social and technical aspects of both centralised AC and the distributed DC electricity systems.
2. Establishing the sociotechnical context through which the transition might have to go, including the decision making process of institutions, i.e. institutional structuration
3. Identifying and critically analyse a theory that will provide the theoretical framework for the transition
4. Establishing a transition pathway based on the data
5. Critically analyse issues surrounding and affecting the transition

The question now arises; given that every country in the world has some sort of working centralised AC electricity system, why would this research seek to replace it with a direct current distributed system?

### **1.3. Context and Motivation**

#### **1.3.1. Global challenges for the 21st century**

Energy underpins most activities of a modern society, and its continual availability is crucial for sustaining the level of living standards expected by modern developed society. Having all our energy needs ‘on-tap’ is something that is often taken for granted. It is only when there is a discontinuity of supply that it is realised how vulnerable we are. The longer a discontinuity, the more our daily lives are affected. Increasing research and resources are going into understanding and finding solutions to many of our modern energy problems. The energy research community is very large and operates in many different academic areas. However, the International Institute for Applied Systems Analysis (IIASA) commissioned a report that brings together energy research from all over the world in one place.

The report is titled ‘*The Global Energy Assessment Towards a Sustainable Future*’ (GEA, 2012): from now on it is abbreviated to GEA. It provides a comprehensive picture of 21<sup>st</sup> century global energy challenges and covers all aspects of world energy. Besides the international editorial committee, it has the input from about 300 authors and 200 anonymous

reviewers from academia, business and government, intergovernmental and non-governmental organisations from all the regions of the world. This gives an international dimension to its key findings and summary chapters. The process of contributing material to the GEA is similar to that adopted by the IPCC (GEA, 2012, p. X). The output from all these contributions can reasonably be looked at as a comprehensive snapshot of world opinion in 2012, when this research began.

The GEA (2012, p. XV) identifies the Global Energy Challenges (GEC) for the 21<sup>st</sup> century. These highlight the problems that underpin the present global energy goals:

*“Since before the Industrial Revolution, societies have relied on increasing supplies of energy to meet their need for goods and services. Major changes in current trends are required if future energy systems are to be **affordable, safe, secure, and environmentally sound**. There is an urgent need for a sustained and comprehensive strategy to help resolve the following challenges:*

- providing **affordable energy** services for the well-being of the 7 billion people today and the 9 billion people projected by 2050;*
- improving living conditions and enhancing economic opportunities, particularly for the 3 billion people who cook with solid fuels today and the **1.4 billion people without access to electricity**;*
- increasing **energy security** for all nations, regions, and communities;*
- **reducing** global energy systems **greenhouse gas emissions** to limit global warming to less than 2°C above pre-industrial levels;*
- reducing indoor and outdoor **air pollution from fuel combustion** and its impacts on human health; and*
- reducing the adverse effects and ancillary risks associated with some energy systems and to increase prosperity.*

***Major transformations in energy systems are required to meet these challenges and to increase prosperity.”***

Furthermore, the GEA (2012, p. 34) identifies a set of more wide ranging Global Challenges for which energy is a critical entry point. These global challenges include “***sustainable economic and social development, poverty eradication, adequate food production and food security, health for all, climate protection, conservation of ecosystems, peace, and security.***”

By 2015 the United Nations (2015) set out similar challenges in what are called the ‘17 Sustainable Development Goals for 2030’ (see Section 6.1 below). Similarly some of the ‘Societal Challenges’ of the EU’s Horizon 2020 programme (European Commission, 2011), are the same as those of the GEA. These are therefore global challenges, that are primarily associated with ‘Sustainable Development’ and ‘Societal Challenges’, but are not identified as ‘energy challenges’. However, whether directly or indirectly, most of these global challenges have a connection to the usage of energy (see Section 6.1). These energy challenges are global; although they do not necessarily all exist in every country, they cumulatively provide the drivers for energy policy around the world. The challenge to provide all citizens with energy that is “affordable, safe, secure, and environmentally sound” is, however, universal. The UK coalition government of 2010 set out what it called its “energy trilemma” which is “The challenge of keeping the lights on, at an affordable price, while decarbonising our power system” (Department of Energy and Climate Change, 2014a). This does not mean that the UK ignores all the other Global Energy Challenges, but rather these are the three main drivers of UK energy policy. Governments all over the world employ energy policies, laws, regulations, and enforcement regimes, which are some of the drivers that shape both the energy systems and the markets in which they operate. Entrepreneurial innovation aimed at providing solutions to these global energy challenges are further drivers that shape the energy system. Therefore, the energy systems we have today are being continually reshaped by entrepreneurial innovation and government policies.

The electricity system could be thought of as belonging exclusively to engineering, as it is in essence a technical system. However, for the safe operation of the system there are many laws, regulations, codes of practice and guidelines, that are all instituted, complied with and enforced by people. People install and maintain the systems and consume the electricity. Therefore, while technical, the wider electricity system has a strong social aspect to it, which identifies it as a sociotechnical system. These social aspects are discussed in Chapter 3 below. Throughout this thesis, how the change to distributed electricity systems can alleviate some of the 21<sup>st</sup> century’s global challenges is considered.

### 1.3.2. Energy is pervasive in modern society

In its basic form, an energy system comprises primary fuels, secondary fuels, and a means of transferring the fuel into a state that can be used to do some sort of ‘work’. The primary fuels can be fossil based (natural gas, coal and oil), bio based (oils from seeds and animal derivatives, and bio-gas from bio-waste) or renewables (solar, wind geothermal, biomass and hydro-energy). Added to the mix is nuclear energy. (The historical and future mix of these fuels from 1950 to 2050 can be found in the GEA (2012, p. 9, Figure SPM-3).) Electrical energy is one of the only types of energy that, besides its traditional usages, can be used to replace other forms of energy for mechanical, heat, and locomotive consumption. Electricity is also an energy carrier; this means that a primary energy source is needed to produce it. The primary energy could be from fossil fuels, nuclear or renewables. The primary concerns for the electricity system are to ensure the availability of primary fuels for production levels that enables the supply that can fulfil daily changing consumption patterns.

In Table SPM-1 of the GEA (2012, p. 7), the global burden of disease from air pollution and energy-related causes is identified. It then goes on to highlight many other 21<sup>st</sup> century challenges that are strongly linked to the energy system:

*“Energy offers a useful entry point into many of the challenges because of its immediate and direct connections with major **social, economic, security and development** goals of the day. Among many other challenges, energy systems are tightly linked to **global economic activities**, to **freshwater and land resources** for energy generation and **food production**, to **biodiversity and air quality** through emissions of particulate matter and precursors of tropospheric ozone, and to **climate change**. Most of all, access to affordable and cleaner energy carriers is a fundamental prerequisite for development, which is why the GEA places great emphasis on the need to integrate energy policy with social, economic, security, development, and environment policies.”* (GEA 2012, , p. 7)

Energy is therefore very pervasive in modern life and underpins many of life’s activities. These activities can be compartmentalised into the following sectors: transportation, infrastructure, industrial, commercial, the office and the domestic built environment. In each sector the challenge is to alleviate any associated Global Energy Challenges in a sustainable and affordable way. Electricity is an essential resource (see Section 2.3) and is therefore inextricably linked to city resilience, sustainability and mitigating the effects of disasters (see Section 2.4). Research focusing on these challenges has been addressed throughout the last

45 years since the first report to the Club of Rome, entitled “The Limits to Growth” (Meadows et al., 1972), see Section 3.5.4 for a further discussion. Nevertheless, the GEA (2012, p. 4) laments, “*Yet, more than a decade into the 21st century, current energy systems do not meet these challenges*”. Therefore, now is the time to have a rethink about how electricity directly and indirectly affects these global challenges. This research identifies the potential advantages of a transition from the present centralised AC electricity system to one where distributed DC systems can be used as a possible partial solution that could mitigate and/or alleviate some of these global challenges. Understanding how such a national transition could possibly take place is the focus of this research.

The literature review identified potential advantages, that a transition from the incumbent centralised electricity system in the UK to a distributed system which are as follows, a more robust system in the face of power cuts caused by natural or manmade disasters, reduction in failure chains and therefore an increase in liveability and living standards (see Sections 2.3 and 2.4 for more details). Furthermore, added to this transition are the advantages of the distributed system being DC instead of AC, which adds the following further advantages, the usage of already available DC compliant technology (Section 2.2.5), reductions in conversion losses, more robust appliances, and an increase in proliferation of renewable systems (see Sections 2.5 for more details).

## **1.4. The electricity system**

### **1.4.1. An historical context to the modern electrical system**

Gordon (1981, P. 15) in, ‘*100 years of electrical supply*’, begins the narrative for domestic electrification with the partnership of Swan and Edison in 1879. Godalming was the first town in the UK to have a public electricity supply system in October of 1881. This was less than a year before Edison set up, in Manhattan New York, his Pearl Street electrical generators in September 1882 (New York Edison Company, 1912). At the outset Edison was generating the electricity in the form of direct current voltage. As his customer base increased further away from his generators it became apparent that, at long distances, distributing DC voltage had the technical issue of voltage drop. Voltage drop is a particular problem in a DC voltage system

because, as it has a constant current, a resistance builds up within the electrical conductor that will reduce the voltage over a long distance. This meant that Edison was not able to supply a guaranteed voltage to his customers who were situated a long way from a generation station. To overcome this problem Edison built more generators that were close enough to his customers to negate the voltage drop problem. However, as his customer-base expanded beyond the island of Manhattan into the New York area of Queens and beyond, there was a realisation that there were inherent disadvantages to long distance transmission of DC electricity. As electricity had to ultimately travel hundreds of miles from where it was generated to where it was consumed, DC voltage became unfeasible.

While Edison continued advocating DC electrical systems, Westinghouse together with Tesla, advocated the use of alternating current electricity systems (McNichol, 2006), which do not suffer from voltage drops like DC electricity (Kinn, 2011a, Section 2.3.6). One way of reducing the voltage drop phenomenon is to increase the transmission voltage of the electricity and then decrease it near to the point of consumption. At that time increasing and decreasing DC voltage was technically challenging. However, between 1878 and 1887 the development of the transformer allowed for the easy stepping up and down of AC voltage (Gordon, 1981). This immediately allowed for long distance transmission of AC electricity and thus allowed the AC generation and transmission of electricity over vast geographical areas. Thus was born the topology of the AC electrical supply and distribution network we have today. The electrical system consists of a centralised generation system connected via a vast distribution grid to the consumer (Figure 2.1). With many generators connected to the grid a centralised control system makes sure that a predictable steady voltage is supplied to all consumers, wherever they are attached to the grid.

While the controversy over which system to use was raging in the USA in the UK the “*Battle of the Systems*” was also raging. In England this battle was between Colonel R. E .B. Crompton and Sabastian Z. de Ferranti, which reached its peak in 1894 (Gordon, 1981, p. 33). Ferranti built a giant AC generation system at the Deptford plant for the London Electric Supply Corporation in 1887. Ferranti’s designs for AC generation system became predominant in the UK.

Edison had to concede to the dominant AC technology. However, his DC systems that were already in place all over Manhattan and Queens did not need to be dismantled. By 1898 (New York Edison Company, 1912, p. 113) Edison was supplying AC electricity to his thousands of customers, and converting it to DC to be consumed as DC voltage. Many of the Manhattan apartment buildings had dual AC and DC electrical supplies in each apartment until the middle of the 1960s. For these customers the Edison Company manufactured DC home appliances. Although for over a century, a centralised AC voltage generation and distribution system has been the dominant and in most countries the only technology, the use of DC voltage electricity has had continual niche applications from the 1880s. In fact, it was only in 2007 that the last DC supply line was cut by the Consolidated Edison company in New York, after which the DC loads were supplied from the AC network via a transformer (Lowenstein and Sulzberger, 2008).

The present electrical system consists of: (1) large centralised alternating current (AC) and direct current (DC) generation systems, (2) a national AC grid distribution network to the built environment, (3) extra high voltage DC distribution links, (4) extra low and low voltage AC distribution network within the built environment, (5) and electrical units (loads) that consume AC voltage and electronic units (loads) that consume DC voltage (Figure 2.1). Therefore, the electricity system provides the researcher with many potential entry points into which to introduce possible changes that could provide solutions to the energy problems of the 21<sup>st</sup> century.

The second half of the 20<sup>th</sup> century saw the inception of the age of the integrated chip and birth of the electronics age. Electronics can only function using a constant voltage and therefore the mass consumption of direct current electricity began. However, over the last 65 years, while the sophistication of the electronics has increased and their power consumption has gone down, they have been supplied with alternating current and have required a transformer to produce, at the point of consumption, the direct current required for their operation. Society is now in the unique situation where the price of renewables has reached a point of economic viability, power consumption levels have drastically dropped and electrical storage devices are reaching affordability. This set of circumstances allows for the introduction of full DC voltage systems within the built environment.



#### **1.4.2. Rationale for concentrating on the consumption side**

Within the electrical system, the opportunities for research are in both the supply side and the demand side. Both sides have potential for research in the technological as well as regulatory/policy aspects of the system. Therefore the question is, which entry point/s into the electricity system could provide possible changes that would alleviate some of the global challenges?

Over the last 30 years the electrical system has changed in many ways. Almost all the changes have been driven by the goal to reduce carbon emissions. Over this time frame, the mix of primary fuels used to generate electricity has seen a reduction in the use of oil and coal and an increase in gas, renewables and some nuclear (Geels, 2014b Figure 3, P. 25). Also energy policy has put greater focus on security of supply for primary fuels (Chaudry et al., 2009; Department of Energy and Climate Change, 2012b). There has also been focus on the introduction of smart technology for the control of the distribution system, i.e. smart grid, smart meters, electricity market reforms (Department of Energy and Climate Change, 2013) demand side response (Ofgem, 2010), and the proliferation of solar panels (Department of Energy and Climate Change, 2014b). These changes have all been on the supply side of the electricity system. Some improvements have also happened on the demand side of the electricity system. For example, major improvements have been made in the transition from incandescent light bulbs to very low powered equivalents, from not so efficient electrical household appliances to ones with very good energy ratings (Energy Saving Trust, 2007), all aimed at driving down energy consumption. Over time, major installations of renewable energy generators have been commissioned, with each generation of technology being more efficient and having greater output ratings. However, as cited above, the GEA states that the energy system still does not meet these 21<sup>st</sup> century global challenges. Therefore, which part of the electricity system has potential to provide alleviation of these challenges?

A new area of innovation uses renewable energy generators to provide direct current voltage to low powered lighting and information technology systems (EMergeAlliance, 2015; Moixa-energy, 2016; Tesla, 2016), see Section 2.2.5 for a discussion about the latest DC technology. At this time, these systems only provide a fraction of the total power needed within a home and have not been extensively researched for their wider potential usage within the built

environment. Given that the technology to provide DC electricity is available from renewable generators, and given that electronic loads need DC voltage to operate, can a whole DC systems approach be a solution to help deal with some of the GEC of the 21<sup>st</sup> century? The idea of using DC voltage for consumption purposes is not new, what is new is the leap from its usage within niche applications to a total DC home. Therefore this research will continue previous research (Kinn, 2011a) and focus on the consumption side of the electricity system.

The present AC electrical system has been in stable operation in many parts of the world for over a century, so how could a transition to a DC system take place? In addition, what would be the technological form of such a system? Could a DC electrical system alleviate the energy challenges of an *affordable, safe and environmentally sound* electrical energy system?

## **1.5. About this research**

### **1.5.1. The approaches of this research**

When energy policy makers use interventionist policy instruments to enact their policies on the generation and distribution industry on the supply side and on manufacturers and consumers on the consumption side, this is called the direct or top-down approach (Roberts, 2012). Unfortunately, as stated above from the GEA, this approach has not been very successful in providing a sustainable energy system that has provided solutions to these global challenges. In fact the top-down approach has been linked to what are called wicked problems, which can exacerbate societal problems (Roberts, 2012).

This research takes the bottom-up approach. It seeks to see if by changing the way electricity is consumed the electricity system can be more sustainable. Furthermore, such a solution may be helpful in alleviating many of the global challenges. This approach is associated with a success in dealing with wicked problems and is further discussed in Section 6.7 below. By changing the technology, it is postulated that these global challenges can be overcome without the need for social marketing (Wilhelm-Rechmann and Cowling, 2008), and messages through the use of negative descriptive norms (Cialdini et al., 1991). For example, negative descriptive norms refer to common behaviours that are undesirable, e.g. “75% of people leave lights on when not at home” (James, 2010).

The word transition denotes many things, which when looked at from a higher aspect incorporate many synonyms (in italics) throughout the whole transition. A transition is a *change* from one state to another. It will depend on how different the new state is from the old state as to whether the move is a *transformation*, *adaptation*, or only an *adjustment* of the old state. The speed and process of change could denote an *evolutionary progression*, a *shift* in a certain direction, or perhaps a continual state of *flux* until the transition is complete. This research aims to identify the processes and progression points within the transition of the UK's electricity system, from the present centralised AC system to one where DC voltage systems are proliferate. It will examine the debates around the topology of the technical system, between a centralised or a distributed system and whether the supply to the built environment should be AC or DC voltage.

### **1.5.2. Contribution to knowledge**

There are three contributions to knowledge that arise out of this research. The first is the development and presentation of a transition timeline, which consists of five phases and many key processes within the transition (see Fig 6.2). The second is the complex sociotechnical characterisation of the 'as is' centralised electricity system in the UK which includes a set of seven social networks (see Fig 3.9). The third is the identification of how society is affected by the loss of electricity, which includes identifying criticalities within the functionality of a city (sections 2.3 and 2.4).

### **1.6. This thesis**

A literature search was carried out to identify previous research that has looked at DC voltage, from the point of view of the electricity system (Section 2.2), DC ready technology (Section 2.2.5), and the social aspects of the technical system (Section 2.4). It was important to understand how, people's liveability (Section 2.3) and a city are affected by the loss of electric power (Section 2.4) and to understand if a distributed topology for the electricity system would be advantageous. Further to this, the potential benefits of changing the electricity system to distributed DC is discussed (Section 2.5). Some interesting gaps have been identified from the literature (Section 2.6), which are analysed within this thesis.

The multilevel perspective (MLP) on sociotechnical transition was identified as an appropriate theoretical framework to help in the understanding of this transition (Section 3.1). The literature review identified some gaps within the understanding of the regime and the landscape of the MLP (Section 3.4). A conundrum within energy transitions is identified (Section 3.5). An attempt is made to address these gaps by further understanding aspects of the sociotechnical regime (Section 3.5.2), landscape (Section 3.5.3) the importance of the carbon debate (Section 3.5.4) and windows of opportunity (Section 3.5.5).

A multi-method case study was identified as the methodology for gathering the data that identifies the processes that will help to construct the transition framework (Sections 4.4 and 4.6). Semi-structured interviews (Section 4.6.3) were used to gather primary data (see Chapter 5). Thematic analysis (Section 5.4) was used on the interview transcripts to identify the key process within the transition. This was followed by the use of the 5Ws plus H approach as a framing device, (these are What, Why, Who, When & How, see Section 4.6.5) to sequence the themes into five phases (Section 6.5) of the transition process, thus producing a 43-year timeline for the whole transition (Figure 6.5).

Researching the transition to DC voltage systems has identified some interesting implications for technical transitioning. These are: knowledge transfer, ownership of transitions within the energy field, complexity of and the direction of approach to, the transition problem, and technical innovations (Section 7.3). While the MLP has been used for a number of years as the theoretical framework to understand historical transitions (Section 3.1), in its present form it is limited as a tool for a future transition. However, through an analysis of the regime and landscape (Section 3.5), this research tentatively shows that the MLP can be used to encapsulate a complex interconnected multi-system problem (Section 7.4.5). It also explores some of the gaps identified in the literature review (Section 7.4). However, this research is a ‘thought experiment’, it looks at a future theoretical transition and is thus constrained by some limitations (Section 7.6). Potential topics for further work have been identified (Section 7.7).

## Chapter 2

# A literature review of the current state of research

### 2.1. Introduction

In chapter 1 the global challenges, which include the GEA's Global Energy Challenges and the UN's 17 Sustainability Goals for 2030, were identified. Distributed DC systems were proposed as a solution that would help alleviate those challenges. At this time the UK's electricity system employs centralised generation and distribution and delivers alternating current (AC) voltage to the built environment. All electronic devices need a constant supply of electricity to function, which can only be supplied via direct current (DC) voltage, which is a constant voltage. Rooftop solar and some wind turbines generate DC voltage that is distributed as AC voltage and is then transformed back to DC for consumption in electronic devices. If electronic devices need DC voltage, why are they supplied AC voltage that needs to be transformed to DC? Are there not advantages to supplying electronic devices with DC voltage? Furthermore can electrical devices operate using DC voltage? Therefore, this research considers the transitioning from the centralised system to a distributed system, and from the delivery and consumption of AC voltage electrical energy to DC voltage electrical energy. In essence, this is a two-stage process, a transition from the centralised system to the distributed system, and from AC voltage within the built environment to DC voltage for consumption.

The research question is, how can the UK transition from the centralised AC system to a distributed DC system? The reason why the transition from a centralised AC system to distributed AC system is not the focus is because supplying DC voltage to the built environment has the some benefits of a distributed AC system, while potentially adding more resilience, efficiency, and a reduced carbon footprint for the built environment. A transition implies changes to the incumbent system, which leads to a changed or new system. Therefore, in essence there are two phases to the transition; the first is the physical topology of the system, huge centralised systems to many small distributed systems and from an AC system to a DC system. The second is a transition that includes changes in the social, regulatory and policy frameworks associated with the electricity system. The electricity

system is, as previously identified (Section 1.3.1), sociotechnical in nature, thus adding complexity to the components of the sociotechnical system that will have to transition.

### **2.1.1. The objectives of this literature review**

Both the energy and electricity systems over the last 130 years have made many transitions, which are part of the continual development and technical advancement of these systems. Developing solutions for the global challenges requires an understanding of the process of transitioning, and how any particular solution can endeavour to succeed where there already exist incumbent systems. The electricity system is one part of the overall energy system therefore, it is important to contextualise a transition of the electricity system within the whole energy system. As this research is trying to understand how a transition in the UK, from an AC electrical energy system to one where DC voltage systems will be able to proliferate, a useful starting point is to ascertain what work has been done so far. This should put into context how advanced the transition to DC already is. However, before doing this, one must understand the difference between a centralised electricity system and a distributed system, and what the physical aspects of the AC and DC systems are. Then, the extent to which the lifestyle within the developed world is dependent on electricity will be discussed. This leads to identifying the vulnerabilities of the present centralised topology of the system, and to assess if a distributed electricity system would provide advantages for the following issues: city resilience, energy independence, energy security, economic prosperity, and the maintenance of the Western lifestyle.

To help understand how the transition can take place, the literature will be used to identify a theory that can be used as the theoretical framework within which this research can be contextualised. The outcome of this review will provide an ability to focus this research within the parameters of any knowledge gaps drawn out from the literature.

This research has identified ten concepts it wishes to gather information about through this literature review, (some are discussed in this chapter and some in the next):

1. To identify the general characteristics and differences between a centralised and a distributed electricity system.

2. To identify the general characteristics of the electrical AC and DC systems.
3. To identify the present thinking/state of research on DC systems.
4. To understand how DC voltage affects the internal electrical system within the built environment, the demand side of the system.
5. To identify the social aspects that are connected to the electrical system, including the many debates/policies that exist within the energy field.
6. To identify why it is important to transition to distributed electricity systems from the point of view of the connection of electricity to living in an urban environment.
7. To identify the benefits of a distributed DC voltage system.
8. To identify any gaps in the literature, which should show where this research sits within the research field of energy transitions.
9. To identify possible theoretical frameworks that will give meaning and understanding to the transition.
10. To see if from the literature it is possible to identify a transition pathway for DC voltage proliferation in the UK.

## **2.2. The characteristics of electricity systems**

### **2.2.1. The centralised and distributed systems**

The model for modern electrical systems consists of: large-scale power stations that generate electricity, a national grid system which delivers the electrical energy to the built environment, and the electrical system within homes, offices, commercial and industrial buildings. The type of electricity delivered is in the form of alternating current voltage and the topology of the system is called a '*centralised system*'. The large centralised generators are fuelled by fossil fuels like oil and coal, natural gas, or uranium in a nuclear reaction. However, with the advent of centralised large renewable electrical generators, it has become possible to generate large amounts of electricity from wind and solar energy to add to the mix of primary fuels now used. The percentage of electricity generated by renewables in the UK, increased from 14.8% in 2013 to 19.1% in 2014 (MacLeay et al., 2015, Table 6A). With renewable generators it is possible to generate either AC or DC electricity, which currently

has to be converted to AC for supply to the built environment, and again back to DC to supply all electronic devices.

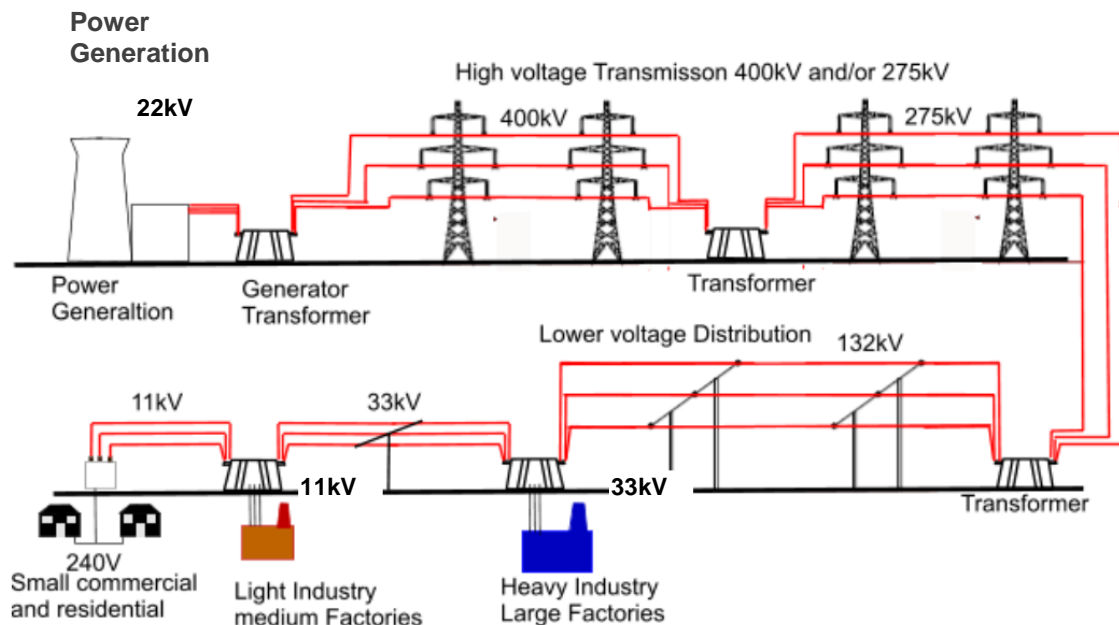


Figure 2.1 Simplified centralised electricity generation and distribution system, showing typical voltages used in the UK (National Grid 2004)

Figure 2.1 depicts an example system layout for the UK's centralised electricity system. However, with the advent of microgeneration systems, for example photovoltaic systems, it is now possible to generate electricity at the point of use without the need for a long distance transmission system. Figure 2.2 shows rooftop solar panels that generate DC voltage and deliver AC voltage electricity via the inverter to the AC voltage mains. This house has a backup battery and could potentially be off grid, or could be also connected to the national grid to receive AC voltage. As this house is generating electrical energy on its roof, this is called a '*distributed*' or '*decentralised*' electricity system.



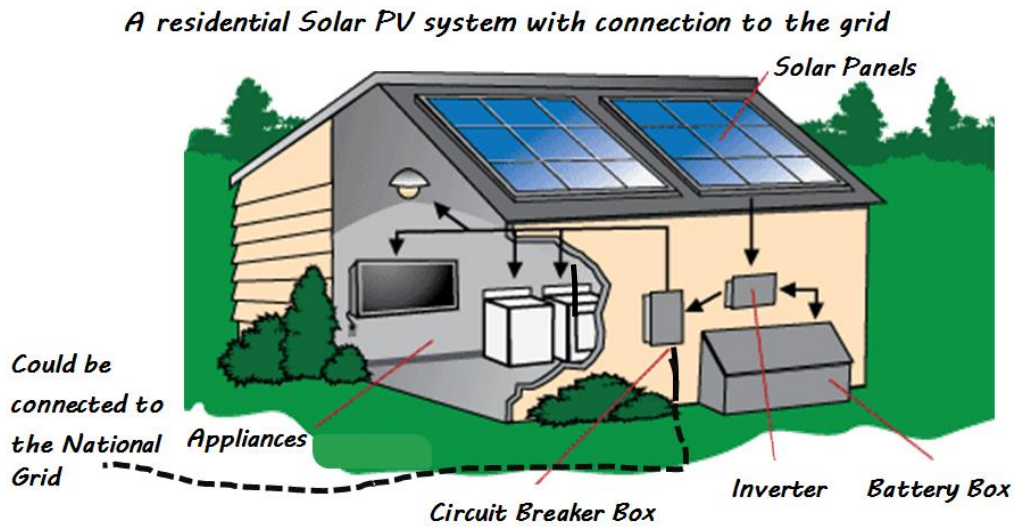


Figure 2.2 Solar generation feeding an AC voltage home.

### 2.2.2. Alternating current and direct current

In the UK, when the electricity comes into a home or office it has a nominal value of 230 V AC and is at a frequency of 50 Hz. The AC is distributed to power sockets that give electrical energy to loads. The loads are appliances, lighting, and everything that needs electricity to operate. The electricity can be either consumed within electrical loads as AC voltage or in electronic loads as DC voltage. Electrical power supplies incorporating transformers are used to change the electricity from AC to DC voltage so that the electronic loads are able to operate. These may include for example: all home entertainment and communication systems, LED and Halogen lights, and fire and security systems.

All electronics need a constant supply of electrical energy to operate. If they are supplied using AC voltage, they would be turning off and on 50 times a second, as AC voltage alternates from a positive voltage to a negative voltage crossing the zero voltage point 50 times a second (red spot in Figure 2.3). Therefore, electronics can only be supplied via direct current voltage, which is a constant voltage (blue line in figure 2.3).

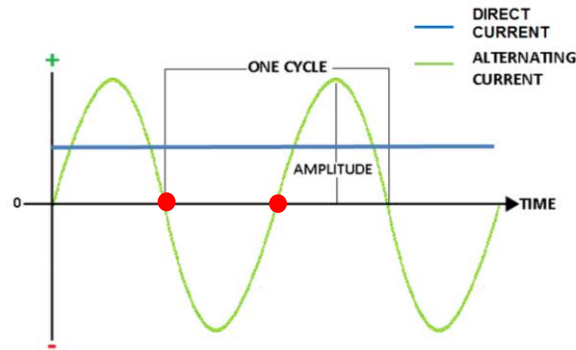


Figure 2.3 Alternating current voltage varies with time while direct current voltage is constant.

### 2.2.3. The electricity system within the built environment

The electrical system within a building can be split up into three components, the supply, the electrical mains distribution system, and the loads. These three components exist both in AC and DC electrical systems. However, the type of hardware used in the DC systems will be different from that used in an AC system. Similarly, the voltage of the DC system can be much lower or much higher than the voltage of the AC system. With extra low DC voltage (which is a voltage below 120V DC (Institution of Engineering and Technology, 2015)), the electrical current will be higher and therefore, the DC system will have to have a different wiring system (Building Research Establishment, 2002). This has ramifications for the ability to retrofit old houses with DC systems without a complete rewiring of the house.

#### (1) The electrical supply system

At this time the AC electrical supply coming into a home is via a 100 Ampere cable that connects to the multiplexer (circuit breaker) board via the (smart) meter.

#### (2) The electrical mains system

In an AC system there is 2.5mm<sup>2</sup> wiring for the power sockets and 1.5mm<sup>2</sup> wiring for the lighting system. For extra low voltage DC electricity, a new set of larger cables of 4mm<sup>2</sup> and 6mm<sup>2</sup> will need to be installed (Kinn, 2011a, Section 5.4.1).

### (3) The loads

Traditionally electrical loads operated on purely AC voltage of 240/230V, however, today almost all AC loads have electronics incorporated in them for control, monitoring or interface purposes. To operate these electronic sub-systems they are supplied with DC voltage via an internal AC-to-DC converter.

#### 2.2.4. Previous work on DC systems

Some of the early history of the centralised AC and DC electricity system can be found in Section 1.4.1 above, with key early milestones shown on the left of Figure 2.4 below. The latest DC technology is discussed in the next Section. Figure 2.4 shows some of the key milestones in the development of the modern electricity systems. The key events of note are: the original electricity systems were all DC, which was superseded by AC due to the difficulty in transmitting DC over long distances, but with the advent of electronic technology, the system has come full circle with the introduction in 2015 of home DC backup systems, which together with solar photovoltaics (PVs) form the basis for the future DC home.

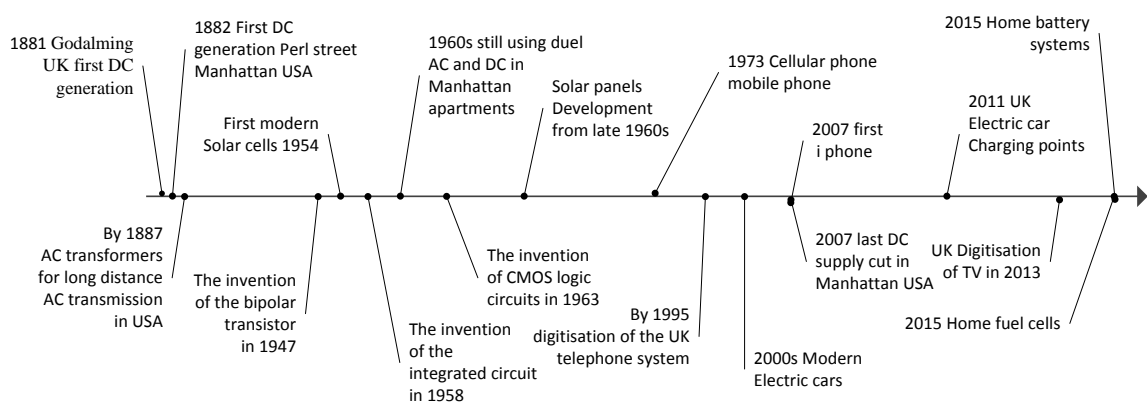


Figure 2.4 A timeline showing major milestones in the electricity system over the last 135 years.

Previous research has been carried out to identify if and how DC can be used within the residential and the office environment. Some researchers looked at identifying a narrow aspect of the usage of extra low DC voltage, (below 120V DC) for domestic use and/or the

office arena (Building Research Establishment, 2002; Friedeman et al., 2002; Ortlepp, 2007; Postiglione, 2001). These researchers were focused on trying to achieve a direct replacement of the AC system with a DC system. Their main criteria were: was it economically viable, and can it be practically implemented. Much of this cited research was carried out in the early 2000s before commercialisation of LED lighting and advances in automation, sensors and miniaturised electronics that are now available. At that time, the research was also focused on identifying a specific mains voltage. Their conclusions were that DC electricity was more relevant for offices rather than for residential, because for domestic use DC was uneconomic and the size of wiring was too large and therefore, impractical for domestic usage. However, later research (Kinn, 2011a), identified in a study that included a wider cost benefit analysis, that domestic DC was technically and economically feasible.

The usage of DC voltage systems is not new, but goes back to before 1977 when the Glenn Research Centre was still part of NASA, and had already installed about 57 off-grid PV and combined PV and wind systems, to provide electric power for water pumps, lighting and/or refrigeration. An example of such a kind of system is the Indian village of Schuchuli Arizona (Bifano et al., 1978) or the Wilcox Hospital Photovoltaic project (Rafinejad, 1983). While the type and amount of DC loads were quite limited, their use of stand-alone renewable energy systems shows that this idea is not new. DC voltage is the standard for space stations (Bercow and Cull, 1991), and satellites (Spear et al., 2004). Much of the electricity systems on warships is DC, some operating at up to 10K Volts DC, which is in the Medium Voltage DC range (MVDC) (Gray et al., 2011; Institute of Marine Engineering Science and Technology, 2007; Kanellos et al., 2015; Kankanala et al., 2012). Much research has gone into low voltage microgrids including for DC voltage (Fregosi et al., 2015; Kakigano et al., 2008; Salomonsson et al., 2007). In the UK there is the University of Bath DC voltage library, and the Bristol SoLa domestic DC project (Kaushik et al., 2014). Data centres across the world use 48V and 380-400V DC, building on this, other research has been carried out looking at DC voltage at 48V and 360V DC or above for use within the built environment (EMerge Alliance, 2013; Garbesi, Vosos, and Shen, 2011; Hammerstrom, 2007; Kinn, 2011a, Section 5.2.1). These voltages are based on technology that already exists for the electrical backbone within data centres. There is also the 30V DC standard for lighting systems (EMerge Alliance, 2013).

The direction for the above DC research has been a top-down strategy, which starts from the supply side. Starting first with the DC microgrid, then the switching and control technology, some niche applications for DC have been developed, but as yet, very little research has taken place on the actual DC appliances. The top-down approach specifies the voltage for the system, (48V and 380-400V), before any DC appliances have been designed. This ‘forces’ the design of the appliances to be able to operate with this voltage standard regardless of any technical efficiencies. Previous research (Kinn, 2011a, 2011b) has tackled the usage of DC voltage in the built environment from the bottom-up, i.e. based on data and calculations about a small pool of known DC appliances, a set of DC voltage curves was developed that could be used in developing potential DC standards. This approach begins with optimised DC appliances and then chooses the most appropriate DC mains voltage for the appliances.

Previous researchers were looking at finding different ways of implementing a DC electrical system that could replicate the present AC system. They specifically looked at the ramifications to the electrical wiring systems and connected infrastructure. However, they did not look at any of the technicalities with regard to standards, voltage specification and regulations that may be needed. Recently, DC systems for domestic and office usage have come to the forefront of current thinking about how to introduce efficiencies and reduce energy consumption. As such in 2015 the IET in the UK ratified a DC Code of Practice (CoP) for the UK (IET Standards, 2015) and the IEEE in the USA is looking into producing a full IEEE DC standard for the home. Within the built environment work continues to deal with designing the DC hardware for the microgrid, and for DC home appliances. Some of the work has been purely market driven (EMerge Alliance, 2013; Moxia-Technology, 2016) while some have been government policy driven (Building Research Establishment, 2002; Garbesi, Vosos, Sanstad, et al., 2011). Some examples of recent research are: the use of inductive technology to cook (Lucia et al., 2013), the Bosch microgrid system for commercial buildings (Fregosi et al., 2015), and the proposed use of DC for some domestic loads (Taufik, 2014).

However, at this time there is no domestic dwelling that uses extra low DC voltage as the electricity of choice for all its electricity consumption as well as for all its energy needs. Most photovoltaic systems use inverters to provide AC voltage for consumption. In fact, within the ‘zero Carbon homes’ (Lester, 2013), ‘*energiesprong*’ (Transition Zero, 2014) and the

*'passivhaus'* (Hopfe and McLeod, 2015) approaches to energy in the built environment, the usage of DC voltage for consumption purposes was not identified. The famous *'Zonnehuis in Castricum'* (Sjoerdsma et al., 1990) an off grid home in Holland', had a DC electricity supply, but supplemented the solar electricity by using gas for heating and high powered domestic appliances. The library at the University of Bath (2015) has 50 computers that operate using DC voltage at 24V DC, but the actual electricity is supplied from the AC mains grid. Many of the DC voltage demonstrators have been specific to extra low voltage lighting systems (EMerge Alliance, 2013; Moxia-Technology, 2016), with those that deal with the whole demand environment being bespoke to their specific needs, for example the 380V DC system used to power a demonstration DC house in Taiwan (Wu et al., 2011).

The above examples show how diverse and long existing the research and knowledge base for different DC voltage systems is. The previous research provides a good set of research methodologies, processes and technology that can be transposed and adapted to be used in the DC home. However, so far, no attempt to create a prototype for a full extra low DC voltage off grid home, that includes the use of DC voltage for electricity consumption and for heating, and provides the same living standards expected by UK residents, has been carried out.

#### **2.2.5. Available technology for the DC home**

An important niche environment where DC appliances are already used is in the leisure industry where the electrical supply is from 12V (car) batteries, (or multiples of). These include fridges, freezers, etc., that can form the basis of the DC home appliances. These appliances use DC compressors motors and pumps that are off the shelf components that can be used to adapt other AC appliances to operate with DC. However, the range of available DC enabled household appliances (RoadPro, 2016), while increasing, is limited compared to the amount of off-the-shelf AC household appliances. Also, the electrical infrastructure available in a vehicle is inappropriate for use in the built environment, due to many technical issues including high currents, thicker cable gauges and very short cable lengths (Kinn, 2011a). However, there are many diverse technologies that are cutting edge and niche, that can be transposed to be used in the residential sector. These are set out in Figure 2.5 below.

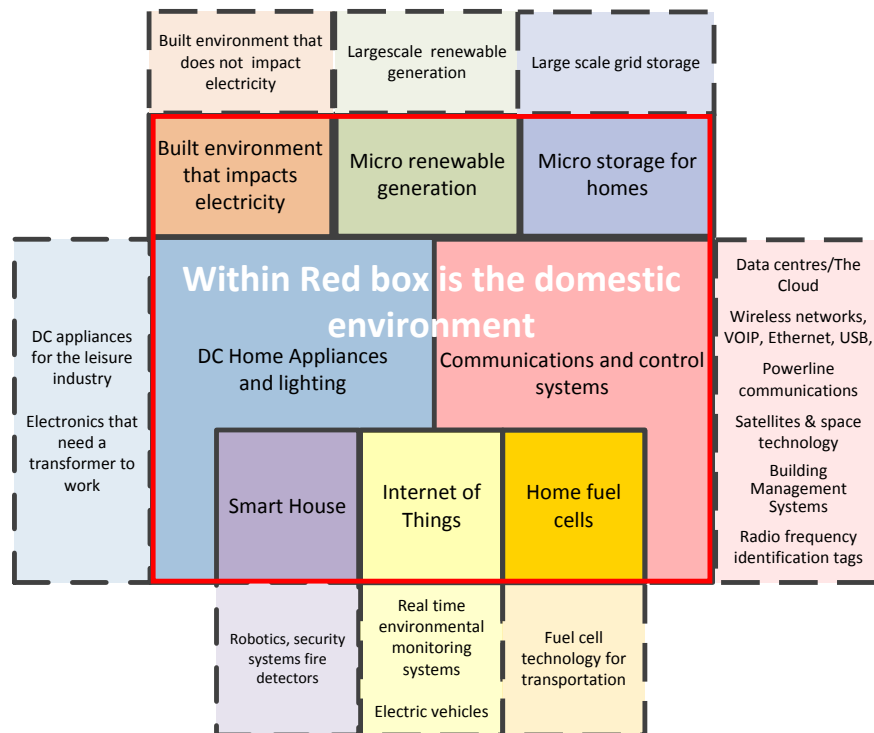


Figure 2.5 Diagram of available technology that could be used in a DC electric home.

The red box in Figure 2.5 represents the requirements within the built environment for these technologies, where outside this box is how the technologies are used for non-domestic applications. At this time much of this DC technology is only in niche applications. Incorporating these technologies into a DC voltage home may be the catalyst they need to proliferate into the mainstream mass market.

Renewable energy technology already exist, however, much of the latest technology is used for centralised large generation of electricity, in wind farms, or solar parks. These technologies are in constant flux, with improvements in efficiency, technology, materials they are made from and they are becoming economically viable (Feldman, 2014). In 2015, the home battery market saw the 'Maslow home battery system' in the UK (Moixa, 2016), the 'Power Wall home battery system' in the USA (Teslamotors, 2016) and 'Solarwatt system' in Germany (Solarwatt, 2016) enter the domestic market. Hydrogen fuel cells have already exited their niche within the petrochemical industry and entered the transport sector. They are now also available for use as micro-generators for the home.

Since intermittent renewable generation has increased, there has been the need to have more control across the national grid that will enable the distribution network operators to balance the system. Therefore, for many years the centralised electricity distribution network has been the focus of smart grid technology (Lockwood, 2013). From this has grown the research into DC microgrid for use within buildings. A lot of the work has focused on commercial buildings, but some has been developed for domestic application (Dragicevic et al., 2016).

The terminology for the technology and methods that are being used to embed and control smart electronics within every day appliances include, home area networks (HANs) (Department of Energy and Climate Change, 2012c) the Internet of Things (IoT) (Lu and Neng, 2010), and smart microgrids. These systems use data communications over wireless, Ethernet, or the electricity mains, which uses Power Line Communication protocols (Amrani and Rubin, 2005; Berger et al., 2014; Khan et al., 2006; Yu-Ju et al., 2002). At this time, in 2016, there are many competing/complementary smart-house technologies. There are many powerline communications technologies, based on the IEEE 802 family of standards (HD-PLC, 2013; ZigBee, 2016) and the HomePNA (HomePNA, 2013) based on IEEE 901 standard. Building management control systems for large buildings already have the ability to monitor and gather data on many characteristics of the building including the electricity system. Data acquisition and control systems include Supervisory Control and Data Acquisition systems (SCADA) (Cherdantseva et al., 2016), and some of the home and building controls technology in KNX and X-10 standards (KNX, 2013; Rye, 2001), as well as many more, can be used within the DC home.

The Maslow system (Moxia-Technology, 2016), concentrates on only using extra-low DC voltage for lighting and computing systems, which has the ability to reuse the pre-existing wiring from the old lighting system. However, this research explores the potential for a house where all loads, not just lighting or very low powered appliances, would be supplied by DC electricity.

#### **2.2.6. Possible solution for the DC home**

For the off-grid all electric DC home, electricity will have to be used to also heat the house. One way to reduce the amount of energy needed is to make improvements to the envelope of



the building. Unfortunately in the UK the housing stock is considered to have low thermal efficiency and, according to Guertler et.al. (2015) is one of the worst in Europe. However, the retrofit agenda has identified how improvements may be made to the existing housing stock (Brown and Swan, 2013). A house that is thermally insulated will require less electricity to keep it warm in the winter and cool in the summer.

The DC system will therefore, employ some of the smart technologies mentioned above. The smartness of the DC system is not only in its ability to do smart things like control lighting, open and close curtains or remotely control devices (Aldrich, 2003). The control system may also be able to act like a smart grid that has the capability to monitor the voltages and currents and make many autonomous decisions about how energy is used (Kinn, 2011b). The control system will consist of a CPU, a mobile phone interface (Liu et al., 2005), communications channels and embedded electronics in every place where an activity will be monitored. This will mean that all switches and wall and light sockets will be replaced with those that have smart embedded electronics. Such a network, if connected to the grid could be part of demand side response capabilities (Parliamentary Office of Science and Technology, 2014a). If the control system employs a power line communications protocol, then data cables may not be needed.

From the electrical engineering point of view, the traditional interface between the load and the power supply, the plug, will change from its traditional shape to one of much smaller size with two or three contacts depending on if earthing is needed. The use of Ethernet cabling and plugs is widespread, with many new houses now incorporating Ethernet sockets around the home. Power over Ethernet, which is IEEE 802.3, at this time is up to a maximum of 100W per cable, if this is to become the standard for DC power and communications transmissions around the home, this maximum power will have to increase. At this time there are no DC standards for the home, therefore, what the actual topology of the system and the specification of hardware for the DC home will be, is not currently known.

There is a large pool of available technologies, some for the home and many for other applications. This means that the transition to DC is not starting with a blank slate, but with a range of technology, methodologies and expertise that can all be adapted and integrated into future all DC voltage electric houses. The challenge will be to scale, adapt, redesign and then

bring all the available technologies that operate at different AC and DC voltages from outside the home into a single integrated package and to fill in all the present gaps in technology. However, electricity by its nature can be harmful to both humans and to the electrical hardware it is connected to. Therefore, in the built environment there exist, statutes, regulations, internationally/nationally recognised standards, protocols and recommendations, to maintain high standards of manufacture, installation, operation and health & safety. Therefore, any major change to the AC system to accommodate the usage of DC electrical systems would require a change in the whole regulatory environment that encapsulates the use of electricity in the built environment.

The usage of DC systems for the built environment is in its infancy, with new progress being made every year. There are no full extra low voltage systems available, or any transition plan for prototypes to proliferate from the demonstrators into wider usage. It is the aim of this study to understanding how the UK can transition from its centralised AC electricity system to a distributed DC system. To do this, the whole sociotechnical system must be understood. This includes the complex and dynamic social aspects of the sociotechnical system and the dialogues and negotiation between the actors that would be required to support the transition. Therefore, identifying from the literature the components of the social aspects of the electrical system is the next step.

#### **2.2.7. The non-technical aspects of the sociotechnical electrical system**

The GEA is an encyclopaedia of concepts about, and the transitioning of, the energy system. However, it does not bring together a characterisation of the energy system from the point of view of sociotechnical systems, i.e. it does not specifically identify the actors, institutions and networks that make up the energy and electricity system. Given the enormous range of literature cited within the GEA, this is therefore, identified as a gap in the literature pertaining to the field of energy and energy systems. However, this research was able to identify, from the narrative of the GEA, many of the institutions and networks that characterise the electrical system and to put together a narrative from the GEA that explains the complexity and need for a broad based approach to energy transitions.

The GEA (2012) was used to identify the non-technical aspects of the energy and electricity system. From its narrative (see Appendix 1 for the extracts), important words and phrases were identified that were connected to actors or actions associated with the energy and electricity systems. Each word and phrase was assigned to an institution and a network. These networks are outside the actual physical electrical system and form part of the social aspects of the electrical system.

Table 2.1 The networks associated with the sociotechnical electrical system

<b>Word from the GEA</b>	<b>Institution</b>	<b>Network</b>
Banking	Bank	Finance
Business	Private finance	Finance
Governments	Government	Finance
Invest	Investors	Finance
Research grants	Funding bodies	Finance
Research funding	Funding bodies	Finance
Government	Government	Policy
Policy	Different policy	Policy
Regulatory	Regulations laws	Policy
Ngo	NGOs	Policy
Research bodies	Any research body	Research and development
Training	Accreditation body	Research and development
University	University	Research and development
Educational	Educational	Societal
NGO	NGOs	Societal
Regulatory	Regulatory	Standards
Habits		Standards
Practices		Standards
Production	Manufacturer	Supplier
Builders	Builders	Supplier
Business	Entrepreneur	Supplier
Utility companies	Utility companies	Supplier
Consumption	End user	User
Energy users	Energy users	User
Skills		
Knowledge		
Interdisciplinarity		
Interaction		
Dialogue		
Communication		
Interactive		

In Table 2.1 seven networks are identified. At the bottom of the left hand column are words that describe the interactions between actors within a single network and between actors in different networks. There may be many institutions that can be correlated with some of these words however; those shown are there in order that a more detailed list of the social networks can be compiled. How this research defines an institution is explained in Section 3.3 below.

There are many interactions between people and the technology throughout the life cycle of the electricity system, these interactions will be affected by the decision to use DC voltage. Therefore, DC voltage not only changes the *technical system* but it will also have consequential effects on *people*; from policy makers, to manufacturers/installers to end users, as well as on the *rules* and *regulations* that surround decision making, installation, maintenance and the end use. There is also the effect this will have on the Global Energy Challenges for the 21<sup>st</sup> century (GEA, 2012, p. 35). Therefore, the whole system, including the non-technical aspects in which the DC voltage is to be implemented, has to be viewed in a wider context as a sociotechnical system, where the importance of who is affected and how they are affected, together with the technical system, will all have to be taken into consideration.

The actors within the networks do not work in isolation: “interdisciplinarity” is a key feature of the system. In fact, the identified interactions and activities are pertinent to many different actors in different networks. The non-technical groups are called the ‘social networks’ of the sociotechnical system. There is therefore, one technical and seven social networks that emerged from the literature:

- Technical
- Finance
- Policy
- Research
- Societal
- Standards
- Suppliers
- Users

So far, the generalised framework of the sociotechnical electrical system has been identified. The question is, all over the world centralised AC electricity systems have been operating for over 130 years, so what are the reasons for wanting to change to a distributed DC system?

### 2.3. Our reliance on electricity

In the developed world people are used to one hundred percent availability of electricity, and in the UK there is a great track record for not suffering major cross country blackouts. This is not so in the USA, who have suffered major blackouts over the last 50 years (Nye, 2013). However, in the modern globalised world, it is important to understand how reliant everyone's daily living standards are on electricity, how economic prosperity is associated with the continuation of electricity supply, and what daily functions within people's lives are affected due to loss of electricity.

According to the GEA (2012, Section 5.2.2, p. 81) about half the world's population now live in urban areas, and it is projected that by 2050 this will reach approximately 6.4 billion people, with a decline in the rural population from 2020 onwards. Therefore, the denser the population the greater the number of people who will be affected by any single loss of electricity. The importance of urbanisation therefore, must not be underestimated within the energy debate. In 2008, the Chinese government predicted that by 2020 up to 65% of its population will be living in cities. Bai (2008) predicted that this would mean 80 new cities the size of Nanjing. The UK is following this trend with cities, especially in the south east where its population is growing, thus the building of brand new cities is on the policy agenda (Department for Communities and Local Government, 2014).

The quality of life for city dwellers, is dependent on a city's resilience, which itself is very much dependant on electricity. Before the effects on a city due to power cuts are discussed (see next Section), it is important to understand what is meant by liveability. Veenhoven (1996) defines the **liveability** of a nation as "*the degree to which its provisions and requirements fit with the needs and capacities of its citizens*". This means that liveability is about the standard of living citizens expect within the society in which they live. Antognelli

and Vizzari (2016), quote Van Kemp et.al.(2003) and make a distinction between liveability and quality of life;

*“However, while quality of life primarily focuses on individuals, liveability is mainly related to the environment (object) based on a human perspective. In particular, liveability theory assumes that perceived quality of life is dependent on objective qualities of landscapes in which humans live (Van kamp et al., 2003)”*

Within a world where people’s whole lives revolve around the need for electricity to ensure daily activities, a good level of liveability and therefore quality of life, is dependent on the continual availability of electricity.

Citizens value liveability and quality of life: this came out from the feedback received by the city of Winnipeg in Canada, when it asked its citizens for their thoughts and visions for future cities (Moir et al., 2014, p. 25). In fact 29 out of 150 city indexes and benchmarks of 2013 were about quality of life (Moir et al., 2014, p. 87; Moonen et al., 2013). The Auckland Plan 2040 and the Melbourne Plan 2050 also have a component that includes liveability. The Melbourne plan is part of the national Liveable Cities Program which the Australian government provided \$20m to fund (Moir et al., 2014, pp. 34-35). This makes the robustness of the urban electricity system and the continuation of electricity supply, critical to the future resilience of cities and to the continuation of the standard of living of the population. Loss of electricity supply can therefore, have major ramifications on liveability.

Almost all electricity generation systems around the world are centralised, with consumers accessing the electricity via a national grid system. Therefore, any failure in the national grid system can have far-reaching indirect consequences, and at a very long distance from the actual point of failure, i.e. a failure chain can ensue.

*“A **failure chain** is a set of linked failures spanning critical assets in multiple infrastructure systems in the city. As an example – loss of an electricity substation may stop a water treatment plant from functioning; this may stop a hospital from functioning; and this in turn may mean that much of the city’s kidney dialysis capability (say) is lost. This failure chain would therefore, span energy, water and healthcare systems.” (UNISDR et al., 2014).*

The potential for failure chains is a key feature of the centralised topology of the electricity system.

A break in the transmission system will affect the whole built environment. Therefore, as the urban population grows an electrical failure will have a larger and increasing impact on the daily lives of more and more people. For example, an uncoordinated turning off of a high voltage line in Germany caused a cascading effect that cut power to 15 million people across Europe, which lasted less than 2 hours (Union for the Co-ordination of Transmission of Electricity, 2006). Or in the USA in 2003 when a tree touched a high voltage cable that caused a cascade event that cut power to 60 million people for a few days (NextGen Energy Council, 2008). This shows the disproportionate nationwide effects that can occur from a small incident if it cascades. There is therefore, a high level of vulnerability in the centralised system.

As this research is trying to ascertain a transition pathway from the centralised system to one where distributed generation is proliferate, it is important to identify how vulnerable a society can be to the breakdown of the centralised system. If these vulnerabilities can be shown to be reduced or eliminated by the use of distributed systems, this would endorse their use. The issues that will be discussed in the next two sections are about the vulnerability of the built environment due to the effects of a power cut within a centralised electricity system, irrespective if it supplies AC or DC voltage. So how are people in a city, and its ability to sustain its level of liveability, affected by the loss of electricity from a centralised system?

#### **2.4. How a city is affected by a breakdown in the centralised electricity system**

In the last ten years, parts of the UK have suffered many incidences of flooding that had been identified as ‘once-in-a-hundred-year events’. These floods have affected many cities and towns along major river networks and have been the cause of blackouts.

In times of a national disaster, when there is a sudden and prolonged loss of electric power, it is possible to record the multiple failure chains that occur due to the blackout, and to understand how aspects of how people’s lives are affected. From this understanding it is possible to identify what aspects of modern living are affected by the loss of electricity and work towards mitigation solutions. The United Nations Office for Disaster Risk Reduction has a global reach in coordinating, campaigning, advocating and informing on the International Strategy for Disaster Reduction (United Nations Office for Disaster Risk

Reduction, 2014). The continuation of the supply of electricity impacts the Priorities for Action as set out in clause 14 of the Hyogo Frameworks of Action 2005-2015. By categorising the damage caused to a major city from a disaster, it will be possible to understand the important role played by electricity in all aspects of the city's functionality.

For the context of this research, the concept of *city resilience* is defined as, '*the ability of the electrical system in an urban area to be more able to withstand outside shocks, and if a blackout does occur to be able to restore electrical power very quickly, so that there is no, or minimal, loss of city functionality*'. This means that if the electrical system is more tolerant of outside shocks, like natural disasters, weather, terrorism etc. and when a disruption does occur, the system can be back on-line very quickly so that disruption to the daily operational activities of the city is minimised, the city is said to have resilience. Therefore, electrical systems that can provide the best resilience and have the least power cuts, should be considered the most appropriate systems.

The use of the word *city* is in line with the internationally recognised nomenclature of *city resilience* (Vale, 2013, p. 93). However, for the purposes of this research and the usage of DC systems the term *city* besides meaning city or town can also include the whole built environment, including single buildings. i.e. *city resilience* could also mean the resilience of a single building.

A review of the disaster literature was undertaken to gather data about how the loss of electricity in a disaster situation affected the functionality of a city during and after a disaster. It was found that the whole field of electricity was largely underrepresented in the disaster literature (Kinn and Abbott, 2014).

However, it was possible to find literature that focused on other aspects, from which important information about the electricity could be assessed. A case study review of the literature about Hurricanes Sandy and Katrina, and tropical storm Andy was carried out. Unfortunately, there was very little information about Hurricane Katrina that focused on anything associated with electricity. While disasters tend not to focus on the loss of electricity, if one digs into the depth of the effects, as is done here, one finds that the loss of electricity tends to lead to major issues.



Hurricane Sandy and tropical storm Allison (which will be referred to as Sandy and Allison) were chosen for this literature review, as they were large scale urban disasters, where the geographical loss of electricity was far larger than the area of physical destruction. There was data about direct physical destruction and direct effects of electricity, and about secondary failure chains caused by electricity or the lack thereof. Also the number of people not able to come back into their homes and businesses post Sandy was small compared to Katrina.

Data about Hurricane Sandy that took place in 2012, came from a report entitled ‘The City of New York Community Development Block Grant – Disaster Recovery (CDBG-DR) Action Plan Incorporating Amendments 1-4’ (New York City, 2013b). The second important case study (Nates, 2004), focuses on an intensive care unit at a hospital that lost total electrical power in 2001 due to tropical storm Allison. To characterise the impact of the loss of electricity on the city, the functionality of the city has been broken up into the following categories and the direct and indirect impacts noted:

1. Housing
2. Healthcare
3. Fire hazards when water and electricity connect
4. Law and order and social impacts
5. Drinking and waste water supply and disposal
6. Economic activities
7. Communications systems

#### **2.4.1. Housing**



Picture 1 Depth of the water at the Red Hook housing complex after Hurricane Sandy.

Many of the buildings affected by Sandy that belong to the New York City Housing Authority (NYCHA) are very large multi-occupancy buildings. In the worst case, the water damage in

these buildings was in the basement and ground floor. Therefore, it can be concluded that the impact to the domestic living conditions for tens of thousands of residents living above the water damaged apartments, was greatly affected by the secondary effect of the loss of electricity and not by the direct effect of the hurricane. The proportion directly and indirectly impacted is not known. The damage statistics identified 402 buildings in Brooklyn Queens & Manhattan that lost electricity which affected over 80,000 people (Table 2.2), and (of which) 386 buildings also lost heat and hot water. These statistics are only for buildings within the public housing belonging to the *NYCHA* and are in a small geographical area (New York City, 2013b, p. 39). This is therefore of great concern for city resilience. Therefore, to really understand the total number of people impacted by the loss of electricity because of Sandy, all other types of housing should also be included.

Table 2.2 People who suffered loss of power just in public housing  
(New York City, 2013b, p. 39)

Area in New York	Buildings	Number of residents
<i>Total in Brooklyn Queens &amp; Manhattan</i>	<i>402+</i>	<i>Roughly 80,000</i>
<i>Broken down by area</i>		
<i>Red Hook</i>	<i>32</i>	<i>6,173</i>
<i>Rockaways</i>	<i>60</i>	<i>10,100</i>
<i>Coney Island</i>	<i>42</i>	<i>8,882</i>
<i>Manhattan</i>	<i>176</i>	<i>41,513</i>

The size of the Red Hook housing complex with its 6173 residents is that of a small town, and not having electric power, heat and water for up to three weeks (New York City, 2013b, p. 94), would have severely impacted the living standards not only of all the residents but also on those who had to negotiate the flood water to help them. At its peak 8.5 million customers lost electric power across many States (Hurricane Sandy Rebuilding Task Force, 2013),

#### **2.4.2. The capacity to deliver medical care**

The healthcare of the residents of New York was affected in many ways. There was the direct danger to life due to the power cut; such as residents who needed dialysis but without elevators were trapped in their apartments (New York City, 2013b, p. 107), and patients in two major hospitals (*“Bellevue Hospital (a crucial level-one trauma center) and Coney Island Hospital”*), that required the use of electrically operated life sustaining equipment, and were

severely impacted by the loss of power. Some people who were in need of medication were indirectly affected as they could not get out of their residence and required public assistance, via mobile medical vans, to receive their medication (New York City, 2013a, p. 7). New patients who were in need of medical assistance had to travel to further medical facilities for assistance, as the two hospitals were closed for four months.

The questions that cannot be answered from these two disaster recovery reports are; what were the direct technical issues at the hospitals that caused the electricity systems to fail? And what technical issues delayed the reconnection of the electric system? Knowing the answers would help to provide a more resilient system during the reconstruction phase of the disaster.

There was also some data from tropical storm Allison, which in 2001 caused a total loss of functionality at the Memorial Hermann Hospital in Houston Texas, which was closed for 38 days. A paper by Nates (2004) gives a rare insight into the impact of the loss of electrical power to the level 1 trauma hospital.

*“In June 2001, tropical storm Allison caused 3 feet of rainfall and catastrophic flooding in Houston, TX. Memorial Hermann Hospital, one of only two level 1 trauma centers in the community, lost electrical power, communications systems, running water, and internal transportation. All essential hospital services were rendered nonfunctional. Life-saving equipment such as ventilators, infusion pumps, and monitors became useless. Patients were triaged to other medical facilities based on acuity using ground and air ambulances. No patients died as result of the internal disaster.”*

This description shows how vulnerable healthcare provision is during a blackout. The reason that there were no fatalities was due firstly to backup battery packs and personal mobile phones, and secondly for some patients, it was the dedication of the healthcare professionals who operated manual equipment on shifts, until the patients could be evacuated.

This disaster put the hospital out of commission for almost four months. The tropical storm was forecast which gave time for contingencies to be put into operation. However, there are many instances where unexpected total blackouts occur for only a few hours, and where ICUs have to go into manual mode to keep patients alive through manual means. In the literature between 1992 and 2010 at least 7 instances are documented of total electrical failure, where even the emergency backup system failed (Carpenter and Robinson, 2010; Fawcett et al.,

2001; Maxwell and Oneil, 1993; Mitchell, 2001; Ohara, 1993; Ohara and Higgins, 1992). The only solution provided by these papers is for better maintained emergency generators and the use of more battery powered devices including lighting.

#### **2.4.3. Fire and flooding**

The utility companies in the United States have contingency plans to cut all power to areas where flooding is expected. This is done to prevent water coming into contact with high voltage electricity. If this were to happen, then besides causing damage to the electrical infrastructure, there can be a catastrophic secondary consequence of fire. See Picture 2 below.

*“Fires also hit a few areas, most severely in Breezy Point where 126 homes burned down and another 22 were seriously damaged.” (New York City, 2013b, p. 94)*



Picture 2 An aerial photo of the 126 burnt houses in Breezy Point New York.

According to the New York 1 News: *“Fire Commissioner Salvatore Cassano said rising sea water made its way into electrical systems at a home at 173 Ocean Avenue.”* (NY1 News)

In the USA, in contrast to most European cities, many of the houses are made from wood and are bungalows. What happened was, as the water encroached into the Breezy Point

neighbourhood, it came in contact with electricity and caused a fire. This fire began to spread from house to house and as the roads were under water the fire-fighters were unable to get their fire-fighting apparatus near the burning properties. They had to use boats to rescue people from buildings that were on fire. In this incident, houses were completely destroyed by what essentially was the secondary effect of the electrical fire.

Although this incident was caused by electricity, the media focus was on the fire, and since there was prior warning of possible tidal surges, the question asked was “why wasn’t the electricity to the whole area cut by the service provider?” However, little has been reported about what can be done to change the electrical system to mitigate against flood water coming into contact with high voltage systems that damage them and could cause huge fires, other than switching it off. This incident also shows vulnerability of the centralised electricity system when compared to a decentralised system. I.e. if every house had a PV system, then all the surrounding undamaged houses that could still be lived in would never have lost power and would have been less impacted by the disaster.

#### **2.4.4. Law and order and social aspects**

The loss of electric power which results in the electrical equipment not being able to operate is a direct impact. However, the loss of the functionality of the equipment provides a secondary effect and may actually have a failure chain effect that leads to secondary public safety, societal and economic impacts.

Set out below were some of the multi-agency solutions that employed a huge amount of manpower to deal with the secondary law and order and social consequences of the loss of electricity;

*“ Enforcement activities including residential and commercial anti-looting patrols, focusing on key neighborhoods around the City that were without power; Regulating traffic, and monitoring citywide gas distribution; During the citywide gas shortage officers were posted at open gas stations throughout the City; Neighborhood patrols and door-to-door checks on residents in the public housing facilities which lost water and electricity; Traffic Enforcement Agents worked overtime to direct traffic in the neighborhoods without power throughout the duration of the power loss.” (New York City, 2013b, p. 115).*

From the solutions provided one can imagine what societal breakdowns could have happened if the city authorities were unable to implement their disaster contingency plan. For example, during a power cut the traffic lights do not work. If we exclude the deployment of skilled traffic officers, within a short time gridlock could occur. This produces delays in people's journeys, in the emergency services getting to where they are needed to be, etc. Gridlock and delays could be ingredients for road rage (Harding et al., 1998; Hennessy and Wiesenthal, 1999), which in extreme cases can lead to injuries and even death. In the USA there is a history of major riots and looting occurring in association with wide spread power cuts, (Nye, 2013). It is not known why officers were posted at the open petrol stations; perhaps a shortage of petrol may have led to civil unrest. Also why many petrol stations were closed and to what extent this was due to the need for electricity to operate the pumps, checkout till, lighting etc. is not known. What is known is that there was, "...a three-week citywide gas shortage." (New York City, 2013b, p. 96).

#### **2.4.5. Drinking and waste water**

The role electricity plays in providing drinking water and removing wastewater is not well understood by the average city resident, and having water on tap is taken for granted. However, due to a prolonged widespread blackout when the tap runs dry and the sewage backs up, it then becomes apparent how crucial electricity is to the movement of water in an urban environment. Below is an extract from the report that shows how the loss of electricity affected the New York water system.

*"Power was lost at many facilities that compose City's drinking water supply system, including a dam and several reservoir control stations. Power was lost at a number of water supply shafts,..."* (New York City, 2013b, p. 109).

*"Of the 14 wastewater treatment plants, 10 were adversely affected by Hurricane Sandy. Most of the damage to wastewater facilities was to electrical systems: substations, motors, control panels, junction boxes and instrumentation. Due to utility power outages, many DEP facilities operated on their emergency generators for up to two weeks. Of the 96 DEP pumping stations, 42 were affected during the storm. Approximately half of the pumping stations failed due to damage from floodwaters, and half due to loss of power supply."* (New York City, 2013b, p. 131).



This report considered the damage to the water system through the eyes of the reconstruction plan. What is known, is that the damage to the equipment's electrical system caused the loss of functionality to the water system. Knowing the exact damage to the electrical systems would help in identifying how a distributed DC system would provide a more robust water system. Some of the damage may have been due to the ingress of sea water into the wires, which can cause degradation of both the wires and the electrical system (Sasaki et al., 2012).

#### 2.4.6. How electricity impacts economic activity and GDP growth



Picture 3 Flooded shops in the UK 2010.

Picture 3 above shows that the water level during some of the floods of the last few years in the UK was not very high. The water level in front of the shops in the far right of the picture seems not to have encroached into the actual shop. As is traditional in the UK, the electricity comes into the building at ground level. For these buildings it is very likely that while the residential parts above the shops were not damaged by the water they still suffered loss of electricity. This could have been mitigated by a rooftop PV system with the electricity meter in the roof. The extent of businesses impacted by Hurricane Sandy was as follows:

*“Around 2,275 businesses were impacted. ... Far Rockaway’s main commercial corridor on Mott Avenue experienced less impactful physical damage, but like the rest of the Peninsula the **long term power outages led to economic loss**. Five months following Sandy, businesses remain closed and of those open, many are*

*struggling to rebuild.” and “...significant losses to industrial businesses, which often keep their valuable equipment on the ground floor ...” (New York City, 2013b, p. 94)*

The extract above is only about one particular area of the Peninsula, which after five months was not back to pre-hurricane conditions. There is no mention about the extent of structural damage and why the businesses remained closed. However, it is assumed that the loss of power may have been the primary cause. Very little is currently known about the percentage of the total estimated economic losses of between \$30 to \$50 billion (Hurricane Sandy Rebuilding Task Force, 2013, p. 19) that was directly due to power losses.

Electricity is not only crucial for people's wellbeing but it also underpins the ability to undertake economic activity, which impacts on a country's ability to grow its economy. The conclusion as to the causality between energy usage and economic growth (GEA, 2012, p. 399) is ambiguous. Lee (2005) concludes, based on data from 18 developing countries, that energy use generally causes GDP growth, while Wang et al (2008), whose work focuses on China, concludes that although they are both interrelated and GDP drives energy growth, energy has little effect on GDP. Research carried out on several African countries (Wolde-Rufael, 2004), found the existence of causality between energy and economic growth in 15 out of 17 countries, however, energy appears to be a smaller factor in economic growth and not as important as labour and capital.

Whatever the view about the correlation between GDP growth and energy, by implication, a power cut will have a negative impact on every economy. In fact when a power cut occurs, whether due to a technical or manmade fault, whether for a few seconds or a few hours, there will be an associated economic cost (NextGen Energy Council, 2008). Andersen and Dalgaard (2013) estimate that power outages between 1995 and 2007 in South Africa “...*show that the economic impact is likely to have been substantial*”. There are estimates for losses in Germany (Growitsch et al., 2015), Ireland (Leahy, 2011), Scotland (Jamash, 2015), and the USA (Balducci et al., 2002) which can be very high for industry. Praktiknjo (2011) estimates the cost to domestic customers in Germany to be on average 15.70 €/kWh, while for commercial, industrial and governmental consumers it is 6.00 €/kWh. Besides the monetary costs there is also the social costs connected to the impact on people's living standards. Work



has been carried out to ascertain people's willingness to pay a premium to avoid domestic power outages (Carlsson, 2008; Leahy, 2011). The latest scheme in the UK is to sign up business customers who are willing to either get paid or pay a lower tariff, if they agree that their electricity supplier can balance their supply system by temporarily cutting them off.

#### **2.4.7. Communications systems**

In the United Kingdom, when analogue telephones were in wide use, they operated on 5 Volts that was powered from the telephone exchange, which used battery backups during power cuts. This meant that people's ability to communicate during blackouts was not affected. However, now, the UK and much of the developed world are moving to a fully digitised world, where the telephone, Radio and Television can all work over the internet. The problem with this is that in times of power cuts all mass communication services become severed, with the mobile phone only lasting as long as its battery life allows. How will governments or public authorities communicate with people in times of disaster if there is a wider spread prolonged power outage? This problem was highlighted by Akerlund (2000), and is the 'elephant in the room' to the resilience community.

All communications devices need electricity, either via the mains or batteries. Therefore, being able to communicate in times of national crisis is a lifeline for the people and is critical in the process of implementing a Crisis Management Plan. The report states that Hurricane Sandy affected the:

*"Telecommunications networks (power outages and flooding resulted in outages leaving thousands without landline, cable, and mobile service)." (New York City, 2013b, p. 96)*

Similarly, in the initial stages of tropical storm Allison vital communications system ceased to function.

*"The interruption of external and internal communications seriously threatens any disaster plan and is in itself a disaster. In our case, the personal mobile phones of medical personnel on call became the primary mode of external communication, and messengers on foot maintained internal communication between departments. Walkie-talkies were of limited use owing to the size of the institution. A limited number of operational cellular phones were used to maintain external communication while batteries lasted." (Nates, 2004).*

It is apparent from these case studies that the centralised electrical systems by their very nature have many points of vulnerability which leads to a failure chain of key infrastructures and thus impacts the citizens' liveability. The question is, can a distributed electricity system enhance city resilience? In addition, can it help deal with the UN's sustainability goals for 2030?

## 2.5. The potential benefits of a decentralised system

Cheng (2009) cites Bruneau et al. (2003) when describing three criteria for infrastructure resilience. Widespread usage of distributed voltage systems supplied by renewable energy generators, should in a disaster situation, meet these three criteria of resilience. The first criterion is '**a system that has lower probabilities of failure**', in a disaster for those buildings/residences not directly impacted by the disaster their electricity systems should not fail at all as they are 'islanded' systems. This therefore, implies that the number of people affected by the blackout is kept to a minimum, thus fulfilling the second criterion of, '**less-severe negative consequences when failures do occur**'. In a conventional centralised electrical system, to reach pre-disaster functionality, the damage to both the centralised electricity infrastructure as well as that to the built environment will have to be repaired. However, in a distributed system only the direct damage to the built environment will have to be repaired, and the distributed systems still operational can be used to immediately begin reconstruction, thus meeting the third criterion of '**faster recovery from failure**'. So how can a distributed system help to build in resilience to the functionality of a modern city?

If one considers an incident like the Haiti earthquake of 2010 or Typhoon Haiyan in 2013, that were mass casualty events, with huge destruction to the built environment, then the best reliable method to keep the electricity flowing is a total distributed system, with many generators, and many paths for transmission. Obviously for such a system to be operational the infrastructure of for example a hospital must be usable. However, the question is, where there is minimal to no physical damage to the built environment, what would have been the impact from Hurricane Sandy or any national disaster, if there was a distributed electrical system? Unfortunately, at this time this is a question for which this research does not have

any data. However, it is postulated that a distributed DC system could help to build in resilience to the functionality of a modern city.

### **2.5.1. Steps towards a distributed system**

The report recommended: “\$250 million to improve resiliency by adding permanent emergency generators at critical NYCHA buildings. Improving the resiliency of the electrical systems is one of the most critical places to begin resiliency work, as these systems are necessary for many other critical services” (New York City, 2013b, p. 49). This is the beginning of implementing a decentralised system. However, this is only for emergencies and not for day-to-day usage.

All but one of the hospital cases cited in Section 2.4.2 above, testified to the need for a battery operated backup communications system. In many of the cases, the staff relied on their personal cellular phones, to communicate between each other within the hospital and with the outside world, in some cases until the batteries ran down, Nates (2004). The batteries act as a distributed system, however, the lifespan of batteries is very limited.

The case literature showed that when implementing a resilience strategy against flooding, putting electrical equipment in the basement and ground floor is not a good idea. The physical layout of the building of the Memorial Hermann Hospital is not known, however, according to Nates, the emergency generators were on the second floor yet the flood water was able to damage them. Therefore, this research recommends that when implementing distributed DC systems, the electrical sub-systems, (multiplexer board, breaker board, voltage controller and meter etc.) should be placed in the loft/roof space, or as high in the property as possible. This enhances Bruneau et al’s three criteria for infrastructure resilience if the water does not reach the electricity control system.

When water gets into the electrical system the low voltage should ensure that the circuit breaker activates without a fire hazard. This may mean that with the isolated generators on the roof (say PVs) the electricity in the upper floors of the building will not be affected. For large apartment blocks like in Red Hook, only the residence on the water damaged floors will be affected. This may help in post disaster reconstruction, thus again fulfilling Bruneau et al’s

three criteria. Since according to Sasaki et al (2012) sea water causes corrosion to cabling, a more robust sheathing and waterproofing should be implemented in flood prone areas. One of the problems in the delays in getting back to normal is the time it takes to restore the energy system, plus the time for the building structure to dry out. If each property has a fully functioning electrical system above the water damage line, then the process of pumping water out and drying out could in theory start straight away post facto, using the available on-site electricity, thus a faster recovery time.

The report stated that “...*enforcement activities including residential and commercial anti-looting patrols, focusing on key neighborhoods around the City that were without power...*” (New York City, 2013b, p. 101) . If New York had had widespread completely autonomous low powered LEDs street lighting systems, and all theft alarm systems were locally powered, then the need for massive manpower to patrol the streets against anti-social behaviour would have been drastically reduced. For the many patients living above the water line who required electrically operated medical equipment, both in the hospitals and at home, such a system would have provided them with electricity and would have mitigated all the logistics needed to help them, again examples that show how distributed systems can fulfil Bruneau et al’s (2003) three criteria for city resilience.

If the electricity supply to the remaining structures is from autonomous electrical systems, then the livability/living standards of those that still have electricity will be maintained, thus increasing the city’s disaster resilience. It will also provide in normal times, an electrical system that can provide a high degree of energy independence and energy security for all its citizens.

So far the literature has been able to identify many advantages of having a distributed electricity system. The question is, what advantages will DC offer for consumption purposes over AC?

### **2.5.2. What does changing to DC add?**

#### **(1) Reduces conversion losses**

Since the advent of the silicon chip in 1947 and the development of power electronics (Meindl, 1997, p. 5), the loads using electricity have developed from purely electrical to electronic applications. This means that more and more loads actually consume DC electricity, even though they are supplied by AC voltage. The conversion from AC voltage is either via an external (black) power adapter, or where internal AC-to-DC transformers are used, it is situated somewhere in the appliance and can be found where the casing feels hotter. Transformers themselves consume energy, and depending on their design and cost, power supplies operate at efficiencies of between 25% and 90%. (Calwell and Reeder, 2002, p. 4), i.e. they do not use, but lose between 10% and 75% of the electrical energy that is put into them. Much of this loss is due to the appliance operating outside the best efficiency of the design and not due to badly designed transformers. At this time micro-generators produce DC electricity which is fed into an alternating current (AC) transmission network via an inverter. In almost all cases this AC electricity is then transformed back to DC to be consumed by electronic devices. Each transformation, depending on the design and quality of the hardware, will cause a loss of energy as no conversion process can be 100% efficient. The best modern power supplies incorporating switch-mode-transformers can be designed with an efficiency of up to 96% (Maswood and Yoong, 2006). However, incorporating switch-mode-transformers into power supplies makes them much more expensive than the mass-produced generic alternatives.

#### **(2) Reduces system components**

If DC electricity is used as the only means of electrical supply, then there would be the advantage of the elimination of the ubiquitous AC transformers in each appliance, which can be up to 25 per household (Calwell and Reeder, 2002, p. 7). Also when DC micro-generators are used, the need for an expensive DC to AC inverter is eliminated. According to Duan and Redfern (2014) for a typical sized PV system of 3.5kW peak, in 2016 the inverter from online retailer Wind Trap costs £1359.00 (Wind-Trap, 2016). Their elimination reduces the amount of energy lost in multiple conversions and therefore, for a given peak load requirement,

smaller DC micro generators will be needed, and the cost for the system will be smaller. Or for the same outlay a larger DC micro-generation system can be installed thus increasing the energy supply. However, they would have to be replaced with electronic DC-to-DC converters, which will therefore, not totally eliminate conversion losses, but which according to Williams (2014, p. 53) is a more efficient converter. DC electrical appliances have less parts than their AC equivalents, therefore, their mean-time-to-failure is lower, and in operation small DC motors, fans, compressors, etc. are much quieter (Kinn, 2011a, pp.113-114).

### (3) Reduces carbon footprint

In the GEA (2012, p. 62) it states that *“Another way to reduce energy use in industry is to use fewer materials, as 70% of industrial energy use goes into the production of materials.”* By eliminating transformers, and increasing their mean-time-to-failure, their life cycle carbon footprint should be smaller than that of an AC equivalent application. Similarly if the plug and socket is designed more like USB or Ethernet, instead of the large plastic and brass 13 Ampere plugs and sockets that are used today, their carbon footprint will be smaller. Another advantage of DC only appliances is, their physical size is smaller and so the amount of materials needed to manufacture them is less, one only has to look at the many iterations of the electronics inside a mobile phone over the last twenty years to see how power electronics is miniaturising all the time.

### (4) Increase in renewable proliferation

Back in 2005 it was predicted by the Energy Savings Trust that by 2050 micro-generation, i.e. distributed energy systems, would account for 30 to 40% of the UK's electricity needs (Allen et al., 2008). This prediction was not based on the usage of DC electrical consumption, but on conventional AC consumption. By adding the energy efficiency that DC can provide, the percentage of the UK's electricity needs that micro-generators could provide could potentially be much higher. By how much, will depend on the final specification of the DC system.

(5) A decrease in energy poverty and an increase in energy security and independence

There are differing opinions as to how to define energy poverty, however, all will agree that the 1.4 billion people who are without access to electricity, and many of the 3 billion people who use solid fuels for cooking and heating (GEA, 2012, p. xv), are in fuel poverty. Much has been written about the subject (Karekezi, 2008; Practical Action, 2012) however, so far this research has not found any suggestion that the use of DC voltage as a means of alleviating fuel poverty is being used. Even the design for solar energy systems have AC loads (Intel, 2011). DC is being used for bespoke niche systems like computers and/or VoIP technology for applications in the developing world (Invaneo, 2016), the DC lights used in the Lighting Africa campaign (World Bank, 2011), and as a niche system for library computers within the UK (University of Bath, 2011). All this increases energy independence and therefore, provides energy security.

(6) A decrease in food poverty

Food has a limited life, and is quickly susceptible to mould-growth and rot. There is both food waste and food lost throughout the food chain (J.Gustavsson, 2011). The current level of food not being consumed, which on a global scale represents a maximum of up to 50% of the 4 billion tonnes of food produced every year (Institution of Mechanical Engineers, 2013), can be reduced with the use of DC autonomous systems. One way of lengthening the life span of foodstuffs is to either dry it or refrigerate it. Both these processes need energy, for which DC voltage systems would be ideal, and can be close to the place of production in rural locations.

Many of these benefits help the global challenges and the UN's sustainability goals for 2030. But can distributed DC electricity systems also be an instrument within the UK's energy policy goals?

### 2.5.3. How distributed DC electricity systems impact the UK's energy policy

#### (1) The *energy trilemma*

The United Kingdom government has what it terms an “*energy trilemma*” which is “*The challenge of keeping the lights on, at an affordable price, while decarbonising our power system*” (Department of Energy and Climate Change, 2014a). It has had for many years an energy policy that is driven by the global challenge to reduce greenhouse gas emissions, much of which is enshrined in law, e.g. The Climate Change Act 2008. Included in its policy is the goal of making energy affordable (Department of Trade and Industry, 2007), i.e. reducing energy poverty, and increasing the amount of renewable energy generation. In the last decade the goal of energy security has come to the forefront due to instability in many oil producing countries and due to restrictions in the supply of gas being imposed as a political weapon (Goldthau and Boersma, 2014; Kinn, 2011a, Section 1.3.2; O’Sullivan, 2013; Riley, 2015). The goal for energy security, has been limited to implementing long term contracts to secure gas supplies and undersea cables to link into the continental grid. One of the goals in UK policy is to reduce demand by increasing the efficiency of electrical loads (Buchan, 2014)

The UK therefore, has a two level priority to its energy policy. The first is to provide energy that is “*affordable, safe and environmentally sound*”, this is fulfilled through its obligations to reduce greenhouse gas emissions and via the electricity market price stability mechanisms used to incentivise the market to invest in new low carbon energy generation (Department of Energy and Climate Change, 2013). The second is to ensure “*energy security*” via its strategy that has focused on ways of securing the primary fuels to produce electricity (Wicks, 2009). Further to this, in 2014, the government has made its first pledge to implement a truly distributed electricity system on public buildings (Department of Energy and Climate Change, 2014b). According to Allan et.al (2015, Section 1) the UK government acknowledges that decentralised energy generation offers potential to deliver lower emissions, increase in diversity of supply, and at lower cost. Thus a distributed system has the potential to achieve a ‘triple dividend’ in terms of meeting energy policy objectives, (i.e. its trilemma).

Across Europe there are domestic retrofit criteria, that if fulfilled, the retrofit must be registered with a government agency, however, none of the 10 criteria in Table 2B8 is the



electricity system (Economidou et al., 2011, p. 82). However, in Croatia for retrofitting they state that distributed electricity must be registered (European Union, 2015, p. 133). Therefore, in at least one European country distributed electricity systems are already on the agenda.

## (2) Energy security

The UK government's thinking behind its energy security policy has not changed, and remains broadly the same as the previous government's policy as presented in the Wicks Report (2009). The energy security policy is based on securing primary fuels, especially gas, through long term contracts and undersea cables to link into the continental grid, but takes little effort in looking at what steps are needed to increase the UK's ability to produce its own energy. The renewable generating capacity in the UK while growing, has shifted from policies to help put solar systems on homes, to offshore and onshore wind farms and now back to large industrial rooftop solar arrays (Department of Energy and Climate Change, 2014b).

## (3) Energy efficiency

The Department of Energy and Climate Change (DECC, superseded in July 2016 by the Department of Business, Energy and Industrial Strategy) was the UK government ministry in which the Energy Efficiency Deployment Office (EFDO), now also defunct, dealt with energy policy and efficiency. One of the main goals in UK policy is to reduce demand by increasing the efficiency of electrical loads. The use of DC voltage as a means of energy reductions was not found in their policy/strategy papers/ reports (Department of Energy and Climate Change, 2012b) As late as November 2012 it was business as usual, "*Our broad assessment of policy framework is that efficiency agenda for households is well covered by existing initiatives...*" (Department of Energy and Climate Change, 2012a, p. 5).

## (4) Reducing energy demand

Reducing electricity demand in housing, which was in 2013 about 35.76% of total UK electricity consumption, is a major issue in energy policy. (Godoy-Shimizu et.al. (2014) said that in 2012 household electricity wastage was 22% or 109 TWh .) The newest strategy is to use demand side response (Bradley, 2013; Ofgem, 2010; Strbac, 2008), via smart metering

(Department of Energy and Climate Change, 2012c) and Home Area Networks (Crossley, 2013) for domestic electricity, and the Capacity to Customers (C2C) initiative for targeted brown-outs (Energy Networks Association, 2013). The C2C initiative involves the customer agreeing to be a low priority for reconnection after a power cut, for this the customer gets a preferential tariff. A further development in demand side response is the use of Short Term Operating Reserve contracts (National Grid Electricity Transmission, 2014), whereby large customers cut 3MW of power within 240 minutes and keep it offline for 2 hours, in order to fill a gap between supply and demand.

It is important to realise the difference between the measured kWh of energy consumed at the demand side of the electrical system and the amount of energy inputted into the centralised electricity supply system. Allen et al (2008) quote from a DTI energy flow chart from 2004, that “...*only 35% of the energy input to the power stations is delivered as electricity to the end user*”. They then point out the importance of distinguishing between the energy value as primary energy and the value of energy available for end users. “*Therefore, 1 unit of energy consumed in the household represents approximately 2.9 units of primary energy input into the power station. It is vital that this is considered when assessing the benefits of installing a micro-generator: it is the **primary energy** that needs to be offset rather than just **the end-use energy***.” However, in a renewable energy system where the primary energy is free and renewable, such conversion losses need not be offset like fossil fuels, this is another advantage of having a distributed renewable electrical system. The approximately 65% (as in 2004) of primary energy losses should not only be taken into consideration when working out the carbon and economic payback periods, but it should also be taken into account over the lifetime of the distributed renewable energy system.

Energy policy in the UK has looked at energy drivers in a much generalised top-down approach and from the national centralised generation point of view (Department for Business Enterprise & Regulatory Reform, 2008b; Department for Business Enterprise and Regulatory Reform and Department of Energy and Climate Change, 2009; Wicks, 2009). Little attention has been given to any radical changes, especially changing from mainly centralised to distributed generation or from mainly consuming AC voltage to DC voltage (Boardman, 2007; Boardman et al., 2005; Energy Saving Trust, 2007). Given that the UK has suffered a

number of once-in-a-hundred-year flooding events over the last ten years, there will be many advantages for the use of distributed systems. Added to this by making the electricity consumed DC, this will add to the resilience of the built environment, and increase the UK's energy independence with energy security.

## **2.6. Gaps in the literature**

During this literature search some gaps in the research and knowledgebase were identified. Solutions for some of the knowledge gaps will be included within the body of this research, others that are pertinent to the transition process of DC voltage systems but are outside the scope of this research, are only noted so that they can be included for further work.

### **2.6.1. The DC system Voltage & DC standards**

The main technical limitation of using DC electricity is the operating voltage. Extra-low-voltage, which is that below 120 Volts DC (Institution of Engineering and Technology, 2015) suffers from voltage drop issues, whereas low-voltage applications up to 400 V DC suffer from unique safety issues, (Kinn, 2011a, Chapter 5), including arcing when switching off the DC power (Swingler and McBride, 2008). There are, therefore, a range of possible values for the DC system voltage. To fill this gap, i.e. which DC voltage to use, research should be carried out on reengineering home appliances for use with DC voltage and analysing them against AC voltage appliances to provide a British Standard for the DC voltage in the built environment. Unfortunately, this work is currently not part of this study.

Extensive research has been carried out on smart microgrids, Big Data which included, home area networks and the Internet of Things, together with DC control and switching technology. However, these researchers take a top-down approach, there is no focus on the actual household appliances beyond those that are normally found in an office, which is lighting and information technology. The availability of DC appliances for the home is therefore, very limited, and a comprehensive standard for DC appliances does not yet exist; this is a gap in the technical aspects of DC systems.

Although much work has been done to illustrate the potential for DC homes and offices – as yet the potential savings are not fully evidenced and additionally the pathways to incorporate DC into the built environment are not fully understood.

#### **2.6.2. The characterisation of the AC system**

Although the GEA report is very comprehensive with regard to energy in general and electricity in particular, very little is discussed about the AC electrical system from the sociotechnical point of view. As it has not been characterised, it is therefore, not well understood in a holistic way. Characterising the AC electrical system within sociotechnical transitions theory is one of the main outputs of this research.

#### **2.6.3. Electricity in disaster risk reduction & management, and sustainability**

While researching the way electricity or the lack of it affects the social fabric of society a literature search was carried out into the academic field of Disaster Risk Reduction and Management, (DRR & DRM). It was concluded that electricity was underrepresented in the literature (Kinn and Abbott, 2014), see Appendix 4 for this paper. Therefore, the importance of electricity as part of DRR and DRM was found to be a gap in the literature that needs urgent future consideration. (See Sections 2.3 and 2.4). For example in the 276 page report produced by The International Federation of Red Cross and Red Crescent Societies entitled “*World Disasters Report: Focus on culture and risk*” (Cannon et al., 2014) the word ‘electricity’ is only mentioned 3 times. Also across the sustainability, global warming, and climate change literature there is a lack of focus on the electricity system within the built environment as a means to deal with these global issues.

#### **2.6.4. The socioeconomic value of distributed DC electricity**

The societal benefits of having an uninterrupted electrical supply are not taken into consideration when evaluating the economic viability of distributed renewable energy generation (Kinn, 2011b, Section 6.7). This means that the socioeconomic benefits of distributed generation are not considered and this is therefore, identified as a gap in the knowledge base for policy makers. This is also mentioned in the GEA (2012, p. 85),

*“Similarly, the potential benefits of renewables are also often not accounted for when evaluating the return on investment, such as increased energy security, access to energy, reduced economic impact volatility, climate change mitigation, and new manufacturing and employment opportunities.”*

#### **2.6.5. A transition pathway for DC proliferation**

The main aspect of the literature search was to see if it would be possible to identify a transition pathway for DC voltage to proliferate within the UK, however, this was not found. Therefore, it is still the basis of this research, to identify how DC voltage systems can be introduced into the UK.

#### **2.7. Summary and conclusions derived from the literature review**

This literature review, as described in Section 2.1.1 above, was carried out to find information about ten concepts that form the parts of the transition process. However, throughout the review other issues, not initially considered in the early stages of the research, were identified.

The second aim of this research (Section 1.2), is to identify transition pathways for the proliferation of DC voltage into the built environment. Transitioning from one system to another involves change. Before it is possible to implement the transition process, the initial system and the final system must be understood. This literature search considered previous work that would give more details about the components of the AC electrical system other than the basic topology of the physical electrical system. However, a full characterisation was not found. It was noted that since the electricity system is sociotechnical, there would be more to just changing technical aspects of the AC system in order to implement a DC home and office system. So while there is some understanding of the basic topology for the wiring of the DC system, no further details were given, including the social ramifications that a change to DC voltage may cause.

The many non-technical/socio aspects of the AC system are well presented in the literature, not as part of a full characterisation of the system, but as standalone concepts. Therefore, they will have to be identified for the transition process. The literature was then used to identify

groups that became the different social and technical networks that characterise the electricity system.

The concept of centralised systems and distributed systems was explored, and many advantages of the distributed system were highlighted. Some of the societal aspects of electricity that are connected to city resilience and disaster management were used to show the vulnerability to modern liveability and lifestyle by the long term loss of electricity. It was concluded that there is a lack of focus within these fields (Kinn and Abbott, 2014), including the top-down approach used by engineers to deal with modern energy and electricity issues.

The GEA states (p. 13):

*“Building-integrated solar photovoltaics can contribute to meeting the electricity demand in buildings, especially in single-family homes, and solar water heaters can cover all or part of the heat required for hot water demand.” Based on the fact that, “Solar radiation reaching the Earth’s surface amounts to 3.9 million EJ/yr and, as such, is almost 8000 times larger than the annual global energy needs of some 500 EJ. Accounting for cloud coverage and empirical irradiance data, the local availability of solar energy is 633,000 EJ.” (GEA 2012, p. 47).*

Given this statistic, this research postulates that even in the UK distributed solar systems can help to fulfil its global energy challenges, especially when integrated into domestic DC voltage dwellings.

There are a set of complex technical and social issues in the extant AC system and therefore, much room for potential failure of the transition. The transition is a very complicated problem, that could be said to have the nature of what is called a “*wicked problem*” (Edgeman, 2015). Therefore, there is a need for a theoretical framework that will help us frame the problem and understand how the transition could take place. This is discussed in the next chapter.

## Chapter 3

# Sociotechnical transition theory

The electrical system has been identified as sociotechnical (section 1.3.1), thus incorporating elements in its many of its constituent parts that are not solely technical. These include networks of actors, rules, standards laws etc. (see Figure 3.6 below). It has also been noted that this transition is therefore complex and could be classified as a wicked problem. Therefore, developing a framework to help in the understanding of how the transition could take place is important for a successful transition. In this chapter, a sociotechnical theory will be chosen and a theoretical model will be developed. Some gaps within the understanding of the regime and the landscape of the MLP (Section 3.4) will be identified. A conundrum within energy transitions is identified (Section 3.5). An attempt is made to address these gaps by further understanding aspects of the sociotechnical regime (Section 3.5.2), landscape (Section 3.5.3), the importance of the carbon debate (Section 3.5.4) and windows of opportunity (Section 3.5.5).

### 3.1. Choosing a theoretical framework – the Multilevel Perspective

The criteria for choosing an underlying theory was that; it had to be able to identify how humans interact with the electrical system, how events outside the electrical system may affect a transition, and how the new DC voltage topology for electrical systems would be able to proliferate and become a major player in the provision of electrical energy, i.e. it had to provide a way of being able to understand how a sociotechnical transition could take place.

Changes to the energy system are driven from one side by changes of the technology and on the other side by economic, ecological, cultural etc. forces.

*“Transformations in energy systems are long-term change processes (decadal or longer) in technology, the economy, institutions, ecology, culture, behaviour, and belief systems. They typically cover all aspects of energy systems, including resource extraction, conversion, and end-use” (GEA 2012, Section 16.1.1.1, p. 1176).*

In the Executive Summary (GEA 2012, p. 1748) the report states that:

*“Energy transitions are, by definition, long-term, socially embedded processes in the course of which capacities at the **individual, organizational, and systems** levels, as well as the policies for capacity development themselves, will inevitably change. From this perspective, capacity development can no longer be seen as a simple aggregation of individual skills and competences or the introduction of a new “technology.” Rather, it is a broad process of change in **production and consumption** patterns, **knowledge, skills, organizational forms**, and – most importantly – in the established **practices and norms of the actors** involved, or what are called **informal institutions**.”*

It goes on to state that:

*“Case studies of the implementation of onshore wind power in Europe and the diffusion of solar home systems in Asia and Africa illustrate that **dialogues** play an important role in developing and institutionalizing capacities for energy transitions. Dialogues may not “solve” problems, but they do open channels for innovative ways to deal with them. For dialogues to work, confidence-building measures that recognize the legitimacy of local concerns, interests, and needs, as well as take account of the informal institutions shaping the behaviour of actors involved in the change process, are essential in gaining broad societal support for an energy transition.”*

These quotes show that to make an energy transition involves many different groups of actors and institutions that are joined by “**dialogues**” that transfer knowledge.

For the transition to DC electricity systems, the following will be required of a theory that will help encapsulate the transition:

1. It should be able to deal with a fundamental transformation within a technical system (transitioning processes)
2. It should be able to include both the technical and social aspects of the system (is sociotechnical)
3. It should be able to help in the understanding of the transitioning process (characterise the system under analysis)
4. It should be able to encapsulate the actors and their decision making processes (actors, institutions, institutional structuration, power, and lock-in processes)
5. It should have the ability to depict the transition process



Ever since Adam Smith looked at the way people worked, researchers have been studying aspects of working practices. Trist (1951) researched how changes in the working methods of coalmining affected the coalminers, and discussed the relationship between “*social structure and technological content of the work system*”. His work was seminal in understanding the relationships between people and technology.

For many years, researchers have been interested in how technological transitions (TT) take place. Case studies include: the transition from sailing ships to steamships between 1780–1900 (Geels, 2002), from a high to a low carbon electricity system (Foxon et al., 2010), changes in the Dutch electricity system (Verbong and Geels, 2007), the transition from humans to machines unloading grain cargo in the port of Rotterdam (Van Driel and Schot, 2005), the transition from traditional factories to mass production in the USA (Geels, 2006b), the transition from horse-drawn carriages to automobiles (Geels, 2005a) and the transition from cesspools to a sewer system in Holland (Geels, 2006a).

This research, which is about a transition in the electricity system, takes place in what Araújo (2014) labels the “*emerging field of energy transitions*” and is part of the emerging field of “*sustainability transitions*” (Markard et al., 2012). It is looking at a transition of a technological system, which is governed by, and exists within, a complex sociological structure. This implies that, the theory that will provide the theoretical framework needed to help formulate a transition to DC systems, will be found in the social sciences.

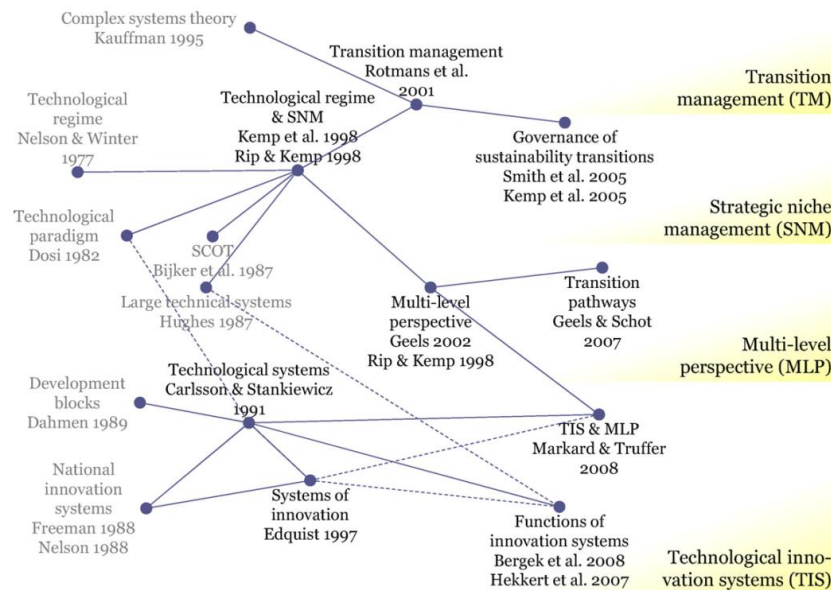


Figure 3.1 The four conceptual frameworks central to sustainability transition studies (Markard et al., 2012).

According to Markard et.al (2012) there are “*Four approaches that are considered to be central for the theoretical framing of sustainability transitions*”, each providing its own conceptual framework. These are shown to the right of Figure 3.1 above. These four areas of research have developed out of many social science theories that could help to understand and contextualise the electrical system, many of which could be used to understand specific aspects of the system.

The theory that best encapsulates most aspects of the five criteria above is the Multi-Level Perspective (MLP) on sociotechnical transitions. (For a further discussion see Section 4.5). Below is a brief outline of the background and concepts incorporated into the MLP theory that shows it is compatible with this research.

Geels (2002) describes technological transitions as:

*“...major, long-term technological changes in the way societal functions are fulfilled. TTs do not only involve changes in technology, but also changes in user practices, regulation, industrial networks, infrastructure, and symbolic meaning or culture.”*

The MLP theory is derived from different analytical theories, (as can be seen in figure 3.1 above), and is described by Geels (2011, Section 2) as follows:

*“The multi-level perspective (MLP) is a middle-range theory that conceptualizes overall dynamic patterns in sociotechnical transitions. The analytical framework combines concepts from **evolutionary economics** (trajectories, regimes, niches, speciation, path dependence, routines), **science and technology studies** (sense making, social networks, innovation as a social process shaped by broader societal contexts), **structuration theory** and **neo-institutional theory** (rules and institutions as ‘deep structures’ on which knowledgeable actors draw in their actions, duality of structure, i.e. structures are both context and outcome of actions, ‘rules of the game’ that structure actions)”*.

In the MLP model of sociotechnical systems transitions “...two views of the evolution are combined: (i) evolution as a process of variation, selection and retention, (ii) evolution as a process of unfolding and re-configuration...”. Geels (2011, p. 26) explains that the uniqueness of his MLP is that it focuses on **concrete systems** like energy, transport, and agri-goods, and focuses “...in more detail on the various groups, their strategies, resources, beliefs and interactions”. Geels has further refined and developed his MLP model over the last fourteen years (2005b, 2011, 2014a, 2014b; 2007; Verbong and Geels, 2007). Foxton (2011) builds on the MLP in his research to develop transition pathways for the UK electrical system. The levels given by Geels in his MLP framework provides for all aspects of the transition, from the inception to proliferation and includes external and internal pressures that affect the transition. Therefore, this research concludes that since it has many aspects that match the full cycle of the sociotechnical transition, the MLP is the best theoretic framework for this transition.

## **3.2. The MLP in detail**

### **3.2.1. Introduction to the Multi-level perspective on sociotechnical transitions**

As the MLP theory has been in flux since Geels’s 2002 paper, set out below in Table 3.1 are the definitions of the terminology used in connection this theory as pertinent at the time of the citations given. However, Markard (2008) in his section 3.2 and in his footnotes of that section, points out that the meaning of some of these terms has changed over the period 2002 and 2008. For further reading about each term, see the sections given in the left column.

Table 3.1 Terminology used in connection with the MLP theory

<b>Term and where discussed</b>	<b>Meaning</b>	<b>Cited From</b>
<b>Landscape</b> Sections, 3.2.2, 3.4.1,	The landscape is an external structure or context for interactions of actors	(Geels, 2002)
<b>Sociotechnical Regime</b> Sections, 3.2.3	The sociotechnical regime is made of different social and technical networks / groups each of which from the outside looks like being a coherent network joined by semi-coherent rule sets	(Geels, 2004; Geels and Schot, 2007; Rip and Kemp, 1998)
<b>Niche</b> Sections, 3.2.4	Innovations need to incubate in an environment that is shielded from the incumbent system This environment is called the ‘niche environment’, the new innovation is called the ‘niche innovation’ and the actors working within the niche can be called ‘niche actors’	(Verbong and Geels, 2007).
<b>Windows of opportunity</b> Sections, 3.5.5	This is the terminology used to describe a change within the landscape level of the sociotechnical system that opens up opportunities for niche innovations to develop.	(Geels, 2002)
<b>Multi-actor networks</b> Sections, 3.5.2	These are the social networks that make up a regime	(Geels 2002 Fig. 2)
<b>Sociotechnical configuration</b> Sections, 4.6	Elements of the sociotechnical system. Includes both the social as well as the technical aspects of the whole system	(Geels 2002 Fig. 1)
<b>Social Networks</b> Section 2.2.7	The label given to the social networks of Geels’s multi-actors networks	This research. This term is used by Geels (2011, Section 2)
<b>Technical Networks</b> Section 2.2.7	The label given to the technical aspects of Geels’s Sociotechnical configuration	This research
<b>Institution</b> Sections, 3.2.6 & 3.3	“Durable systems of established and embedded social rules that structure social interactions. In short, institutions are social rule-systems, not simply rules.” Examples given (on page 15), are language, money, laws, government, contracts, and the institution of marriage.	(Hodgson, 2006, pp. 13-15) This definition differs from that found in Geels 2004 page 899
<b>Structuration</b> Sections, 3.2.6	The active making and remaking of social structure. This means that all social action presume the existence of structure. But at the same time structure presumes action, because structure depends on the regulation of human behavior	(Giddens, 2006)

<b>Institutional Structuration</b> Section 3.2.6	The mechanism whereby actions can take place within the structures of an institution.	This term is used by The following (Lammers, 2003; Landry and Amara, 1998; Scott, 2000)
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The MLP sociotechnical model describes a three level framework of analytical concepts to help understand the complexity of sociotechnical change, and is based on many papers by Kemp, Rip and Geels and others (Geels, 2002, p. 1259). It consists of three levels, the *landscape*, the *patchwork of regimes* and the *niches* Figure 3.2. The **landscape** provides the influences that put pressure from ‘above’ on those who operate in the regime level. The **niches** are spaces that are protected from the **regimes** where emerging innovations can develop. For innovations to succeed they must identify and take advantage of ‘windows of opportunity’ to change aspects of, or the whole, regimes. (For a discussion about the terminology ‘windows of opportunity’ see Section 3.5.5 below). A changed regime should be able to enable change at the landscape level (Genus and Coles, 2008, p. 1438). When a niche innovation succeeded in moving into the regime this is essentially the process of a transition. The landscape is also called the *Macro-level*, the patchwork of regimes is called the *meso-level* and the niches form the *micro-level*. The niche and the landscape are defined in relationship to the defined regime under discussion, and as such are seen as ‘*derived concepts*’ (Geels, 2011, p. 26)

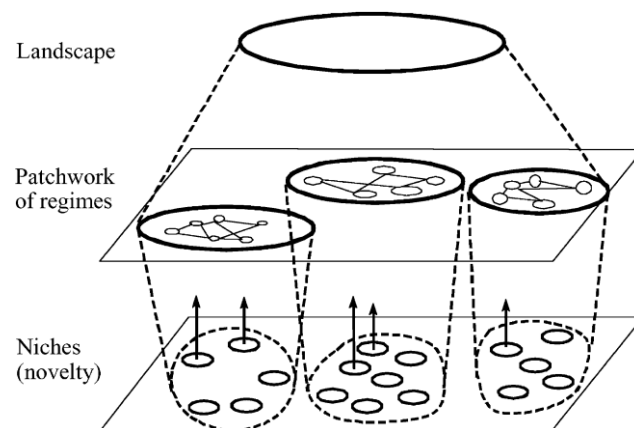


Figure 3.2 The multiple levels as a nested hierarchy the MLP (Geels, 2002, Fig 3).

### 3.2.2. The Sociotechnical Landscape

Geels (2002) explains that the landscape “*contains a set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems. The landscape is an external structure or context for interactions of actors.*” During the early phase of the MLP model, papers on this subject characterised the sociotechnical landscape as being in a stable state or as a very slow moving state, and has been compared to the physical ecological landscape (Van Driel and Schot, 2005). However the description of the landscape was criticised as being a “*residual analytical category*” (Geels, 2011, Section 3.6). The later description of the landscape level differentiates three types of landscape dynamics (Geels, 2011):

*“(1) factors that do not change (or that change very slowly), such as physical climate, (2) rapid external shocks, such as wars or oil price fluctuations, and (3) long-term changes in a certain direction (trend-like patterns), such as demographical changes.”*

### 3.2.3. The Sociotechnical Regime

The concept of regime associated with technical systems goes back to Nelson and Winter (1982, pp. 258 -259) who used the term ‘technological regime’ to describe technicians’ beliefs about what is or is not feasible or worth attempting when looking at a basic or dominant design of an engineered product like a plane. In a given regime engineers focus their innovation on improving major components or aspects thereof. It is further discussed elsewhere (Kemp et al., 1998, p. 176) as follows:

*“In each industry, a dominant design emerged which served as the basis of development work, both inside and outside the industry. It served as a model for development, by defining an outlook or frame of reference for engineers, and enabled standardization, so that production economies can be sought...An important characteristic of the concepts of technological paradigm and technological regime is the existence of a core technological framework that is shared by a community of technological and economic actors as the starting point for looking for improvements in product and process efficiency.”*

Geels (2002) goes further and describes the technical regimes as made up of engineers and firms who share similar routines, which leads to a technological trajectory, i.e. they move in the same direction to fulfil their engineering goals. Rip and Kemp (1998) widened the

technological regime concept by defining it with the sociological category of ‘rules’. Geels brings these two conceptualities, Nelson and Winter’s ‘*technology*’ and Rip and Kemp’s ‘sociological *concept of rules*’, together to form the concept of the ‘*sociotechnical regime*’. The sociotechnical regime is made up of different social groups as well as engineers, who are joined by a set of semi-coherent rules. Each social group forms a network of actors who are joined to form a regime. Geels’ Figure 2 depicts one multi actor network that exists in one regime of the “*patchwork of regimes*”, Figure 3.3 below.

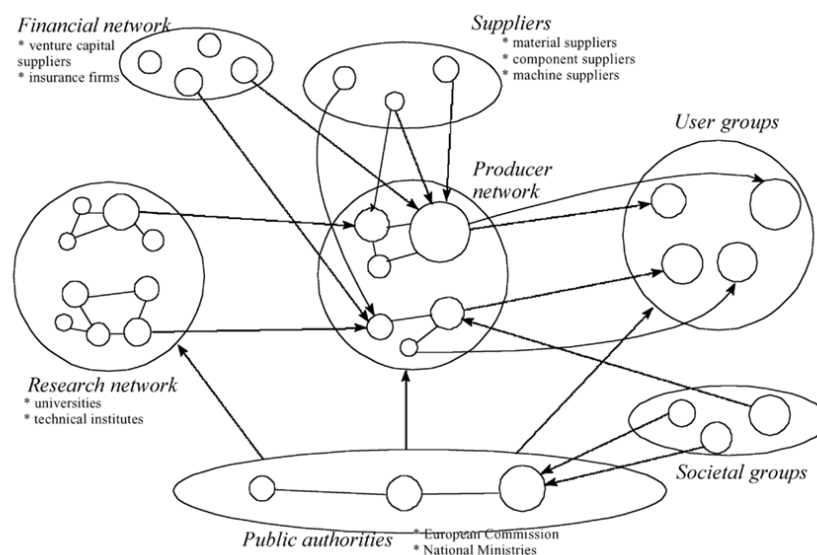


Figure 3.3 The multi-actor networks involved in a sociotechnical regime (Geels, 2002 Fig. 2). Some (Berkhout et al., 2004; Genus and Coles, 2008; Markard, 2008) have criticised the “wooliness” of the term ‘regime’, since depending on the topic of research, the regime and shifts in the regime, have different meanings. For example, if the research is looking at the energy system as the sociotechnical system, then if the focus is the primary fuels then the content of the regime could be coal, oil, or gas, but if the focus is types of generation then the content of the regime will be renewables, nuclear, and fossil fuels. A large shift in the availability of a single primary fuel ‘coal’ may not have much of an effect on the provision of energy to end users. Therefore, they claim that the regime level in the MLP lacks operationalization, specification and delineation (Geels 2011).

Geels however explains that in any sociotechnical system under discussion the MLP is precise about the definition of ‘regime’ and he makes a distinction between it and the ‘system’.

*“System then refers to tangible and measurable elements (such as artefacts, market shares, infrastructure, regulations, consumption patterns, public opinion), whereas regimes refer to intangible and underlying deep structures (such as engineering beliefs, heuristics, rules of thumb, routines, standardized ways of doing things, policy paradigms, visions, promises, social expectations and norms)” (Geels 2011, p. 31).*

He points out that in many empirical studies the use of the label ‘regime’ is used as shorthand for ‘system’, because scholars are more interested in the macro-patterns of transitions than the micro-sociological dynamics of a transition. Therefore, the *“regime is an interpretative analytical concept that invited the analysis to investigate what lies beneath the activities of actors who reproduce system elements.”* Thus further theorisation is needed to fully understand what is happening deep within the regime level. The elements that come into play and provide a framework whereby changes in actor activities can take place, thus triggering the process of a technical transition, can be understood through the eyes of Institutional Theory and Structuration Theory (see Section 3.2.6 below).

The MLP does not restrict the scope of the empirical topics under research, therefore the concept of regime can be applied to different analytical empirical topics. What is important is the definition of the scope by the researcher. One study may look at the primary fuels and apply one type of regime, while another may look at the delivery system. Depending on the delineation of the scope of the research, the social networks that make up the regime level will be defined and therefore different.

The regime is made of different social networks/groups each of which from the outside looks like being a coherent network joined by semi-coherent rule sets (Geels, 2004; Rip and Kemp, 1998). However, *‘there are often tensions, disagreements and conflicts of interest’* (Geels, F. 2011), not only between different actors in the same social network/group but also between different social networks/groups. To understand what provides the strength, stability, internal alignment and homogeneity to the regime level of the MLP it is important to understand the institutionalisation and structuralisation of the social networks/groups that make up the regime. (See Section 3.3 below)



### 3.2.4. The Sociotechnical Niche, the environment and its actors

Innovations need to incubate in an environment that is shielded from the incumbent system (Verbong and Geels, 2007). This environment is called the ‘niche environment’, the new innovation is called the ‘niche innovation’ and the actors working within the niche can be called ‘niche actors’. The development of electric and hydrogen vehicles by the car industry (Bakker et al., 2012; Budde, 2012), shows that the niche does not necessarily need to be outside the incumbent regime, and that the actors can be in the regime and the niche at the same time. To flourish the innovation has to be protected, financially supported and nurtured (Konrad, 2012).

Niche environments are crucial for transitions to occur because “they provide seeds for systematic change” (Geels 2011). The process through which a niche innovation will succeed is explained by Geels and is illustrated in his Figure 1 (Geels and Schot, 2007), Figure 3.4 below. The niche innovation makes changes to the incumbent regime that if successful in alleviating the landscape pressures will proliferate.

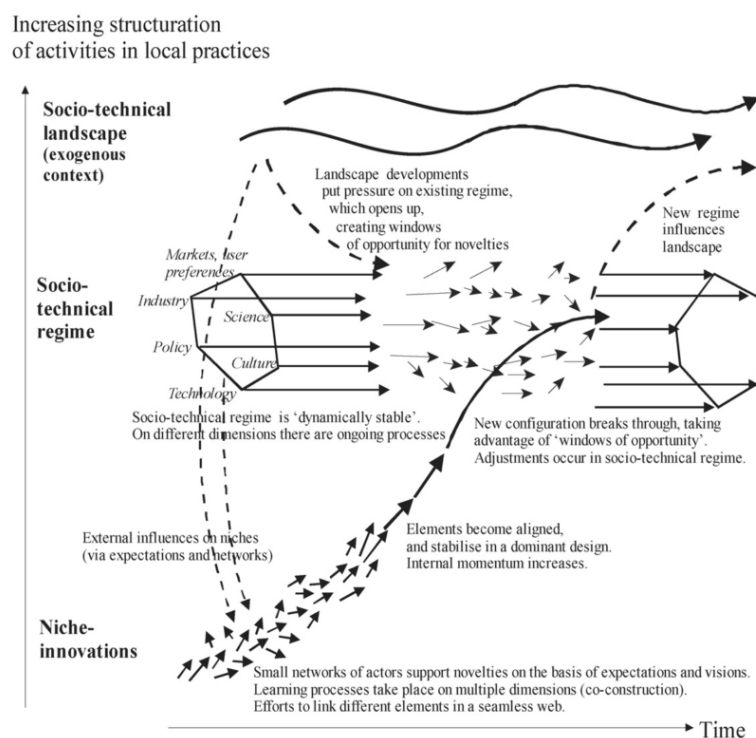


Figure 3.4 The process of sociotechnical transitioning (Geels and Schot, 2007, Fig.1).

Three core processes are articulated in the literature (Kemp et al., 1998; Schot and Geels, 2008) that have to occur for a niche innovation to succeed. These are described by Geels (2011, p. 28) as follows:

*“• The articulation (and adjustment) of expectations or visions, which provide guidance to the innovation activities, and aim to attract attention and funding from external actors.*

*• The building of social networks and the enrolment of more actors, which expand the resource base of niche-innovations*

*• Learning and articulation processes on various dimensions, e.g. technical design, market demand and user preferences, infrastructure requirements, organisational issues and business models, policy instruments, symbolic meanings”.*

### **3.2.5. The process of a technical transition**

Change is a movement from one state to another. This change may be in ideology, practices, working conditions, methodologies etc. For a technical transition (TT) to take place there is often a shift in many of the actor networks (As shown in Figure 3.3) across the whole sociotechnical regime. The regime by definition is in a stable state that is usually in place due to lock-in. For a transition to occur it will have to overcome barriers to change. TTs are non-linear processes and will often be a result of multiple interactions of changes across many of the social networks. Therefore, the result of a transition will be a shift from the incumbent regime to a new regime.

In early MLP theory, change took place from the bottom up, i.e. due to the niche innovation. However, Geels (2011) modified this thinking to include changes caused by the landscape pressure. The extent of how the new regime will differ from the incumbent will depend on the nature and timing of the change. Based on his previous work (Geels and Schot 2007), Geels (2011) articulates the following four ‘pathways of change’:

1. *Transformation:* If the niche innovations are not well developed at the time the landscape pressure is exerted, actors may modify their activities so as to negate the niche innovation, thus causing a gradual adjustment of the regime to landscape pressures.

2. *Reconfiguration*: When the niche innovations are more developed at the time the landscape pressure is exerted, then if they are symbiotic to the regime, actors will incorporate them as add-ons to solve a local problem. This can trigger a change in the basic architecture of the regime.

In these two transition pathways the niche innovations are not or were not able to develop as a competitor to the incumbent regime, and as such do not lead to a new regime, but rather to a changed one. However, the next two pathways lead to a completely new regime.

3. *Technological substitution*: When the niche innovations are more developed at the time the landscape pressure is exerted, and if they are in competition with the incumbent regime, if they succeed in proliferating they will replace the incumbent regime with a new one. Another way they can replace the regime is if they gain high internal momentum, by being successful and attracting resources, finance, market share etc. This may occur without the help of landscape pressures.
4. *De-alignment and re-alignment*: Major landscape pressures cause disintegration of the regime (de-alignment). Multiple niche innovations take advantage of the space to proliferate. Until there is a market winner uncertainty ensues, but when it emerges a re-alignment will occur, which will lead to a new regime.

For the first three it is not clear at what stage of change a new regime would be declared, i.e. how much change or difference does the state of the regime after a transition have to be, before it is declared a “new regime”? The answer may lay in how the regime was initially defined.

One of the outcomes of this research will be to identify which one or more of these transition pathways will be a route for the transition from the incumbent AC voltage electrical system to one where DC voltage systems will dominate. As explained, the regime is made up of many actors (Figure 3.3 above), and each group or network is made up of institutions. Each institution operates within its own defined structures. However, how are institutions defined and how does change occur from within and from without in order to facilitate the transition process?

### 3.2.6. How is an institution defined and what is its structuration?

The best way to explain what an ‘institution’ and ‘structuration’ are is through an example, as a member of The Institute of Engineering and Technology (IET), this institution has been selected. In society, there were people with similar interests who spent their time, working, gathering knowledge and undertaking experiments that concentrated on telegraphy that needed the use of electricity to function. By 1871 the founding fathers “*felt that their profession had attained such a standing that its needs were inadequately met by the other bodies*” (Institution of Engineering and Technology, 2014). They formed The Society of Telegraph Engineers (STE). The society formulated itself with a management structure, rules and regulations that defined its aims and objectives, and who could be a member, in essence it took on the shape of an ‘institution’. However, it did not use the name ‘institution’ until 1889.

The institution incorporates a group of people who operate within a specified structure that is governed by rules, regulations and practices to fulfill a specific purpose. In order to define and fulfill the purpose of the institution, the officers that made up the original management team, as well as all management teams until today, have to put into place these structures. Receiving the Royal Charter further provided the structure for the IET. Formulating the structure of the institution and making any changes to this structure can be described as management ‘actions’. Included in these actions will be the policies and activities that the institution carries out on a daily basis. These may be directed to the internal operational activities of the institution or they may be on the activities that involve fulfilling their objectives. For the IET this may include workshops, conferences, dissemination of knowledge in print or electronic form, presenting information to policy makers etc. Over time the structure of the IET changes according to the actions of its management, employees and members.

Hodgson (2006, p. 13) takes this one stage further and explains that an institution does not need to look like the IET but is defined as “*durable systems of established and embedded social rules that structure social interactions. In short, institutions are social rule-systems, not simply rules.*” He goes on to explain that many institutions are dependent on other institutions to sustain and support them. Examples given (on page 15), are language, money, laws, government, contracts, and one which everyone will recognize, the institution of

marriage. All these institutions have their own rules and social norms that keep the ‘institution’ functioning. His example of institutional breakdown is if money is forged and “*allowed to endure, bad money will drive out good*” therefore the institutions of government, law and enforcement act together to uphold the institution of money. This definition of an institution therefore includes anything that has rules and a framework that governs its functionality and is the definition used by this research. This definition differs from that found in Geels (2004, p. 899) where he states that “*It also happens that institutions are wrongly equated with (non-market) organisations*”.

Giddens (2006) coined the word “*structuration*” which describes the change in the structure of an entity (social) due to the actions of people.

*“...a useful term for analyzing this process of the active making and remaking of social structure is **structuration**,” it always presumes the ‘duality of structure’. “This means that all social action presume the existence of structure. But at the same time structure presumes action, because structure depends on the regulation of human behavior” (Giddens, 2006, p. 108).*

*“In institutional theory, structure is often used as an umbrella term for things that influence an actor’s cognition and behavior as well as the diffusion of practices, e.g. regulations, norms, values, culture, actors or practices.” (Fuenfschilling and Truffer, 2014, p. 774).*

Over time, as an institution evolves, its structure becomes stabilized, solidified and in many cases focalized, which produces a locked-in structure whereby actions are “within the box”, potentially becoming barriers to any fundamental changes that the institution may need to make to keep up with ongoing trends. This locked-in thinking and working practices can lead to ‘institutionalisation’ whereby only actions that conform to present structures are incorporated in its formal structure. The degree of institutionalisation will depend on the ability of actors to make changes to the structure of the institution. Hodgson (2006, p. 16), refers to this as the ‘*degree of agent sensitivity*, within an institution.

Many MLP scholars, while acknowledging the importance of structuration and institution theories, only focused on the macro conceptualisation of this and did not drill down into the structures of social networks of the regimes they studied in order to understand the inner workings of transitions. Recent work has drawn on Institutional Theory to look at the structure and degree of structuration within sociotechnical systems, to understand long term

transformations of sociotechnical systems (Fuenfschilling and Truffer, 2014). They have thus opened up a further layer of understanding of the inner workings of the social networks that make up the regime level of the MLP. This will help to understand transition dynamics.

*“The systems concept emphasizes the interdependence and co-evolution of material and social structures, such as policies, culture, technologies or markets, which over time evolve into a stable configuration that enables the fulfilment of a societal function like water or energy provision. The main challenges for a transition are thus to overcome the rigidities and path-dependencies of already existing, highly institutionalized system structures and to build up new, more sustainable ones”* (Fuenfschilling and Truffer, 2014, Section 1).

The conceptualisation of ‘system structures’ at the heart of the MLP regime level, underlines the importance of institutional theory in understanding how technical transitions are to overcome the lock-in that pervades the strongly inert sociotechnical regime. What is important to understand is the “*content and coherence of the structures*” and “*the degree of institutionalisation*”.

*“The description and assessment of structures within sociotechnical systems represents one of the core weaknesses of the empirical application of the MLP,”* however institutional theory gives the “*vocabulary and methodology to analyse structures and structuration processes.*” (Fuenfschilling and Truffer, 2014). They state that the levels in the MLP can in relative terms be differentiated ‘by the degree of structuration’, the landscape is ‘very strong’, the regime is ‘strong’ and the niche is ‘weak’. The degree of the strength of the structuration can be assessed by identifying the degree of institutionalisation of the core elements that make up the levels in the MLP framework. The coherence and stability of the regime will depend on the relative strength of its structuration, the greater the coherence and stability the stronger the institutionalisation and therefore the harder it will be for a transition to occur.

Therefore to identify pathways for change whereby a niche innovation like DC electricity can become mainstream, the structuration and institutionalisation of the social networks that make up the AC electrical regime will have to be identified and understood. By doing this it will be possible to identify what mechanisms exist, and which people are important to introducing actions that will change the structure of institutions in the social networks of the AC regime. It will also be possible to identify the barriers to change, and possible ways to overcome or

circumvent them. Understanding and mapping the cumulative change across many of these social networks should open up pathways that will facilitate the breakthrough of DC voltage systems into mainstream usage.

However, trying to change the electrical system that is over 130 years old, that is in working order, and functions to customer expectations, will meet some resistance. Therefore understanding the inertia of the system, understanding what barriers to change may exist, and understanding the concept of lock-in may help to identify ways of overcoming any opposition.

### **3.2.7. Sociotechnical lock-in**

Given that the electrical system is sociotechnical, a far-reaching transition, such as to DC electricity will require widespread changes across the whole regime. Invariably, there will be resistance to some or many of the changes needed for the transition to take place that will be due to what is called 'lock-in'. 'Lock-in' is usually concept specific, but as a concept it can occur anywhere. Some examples include, technological lock-in, a firm or institutional lock-in (Foxon, 2002), locked-in beliefs, locked-in social practices, locked-in ways of thinking, locked-in to a living standard, locked-in to substance dependence, locked-in to contractual agreements, time dependant lock-in etc. Many of these, while not seeming to have any connection to electricity, are in fact closely associated to the sociotechnical electrical field. Lock-in implies an inability to change within the ordinary functioning of the sociotechnical system, therefore to overcome this lock-in outside influences or help will be required. Since this research is looking at a transition in a sociotechnical system, lock-in can exist in both the social component as well as the technical component of the system.

Foxon (2007) associates technological and institutional lock-in with a sociotechnical system. He builds on the work of Arthur who discusses the evolvment of a technology to achieve complete market dominance (Arthur, 1989). In general, a technology that by chance gains an early lead and is adopted may corner the market, thus locking out other potential technology. By implication it will itself become locked-in and leads to others having to follow the same technology and being therefore 'path dependant' on historical decisions within the market (Liebowitz, 1995). This may not necessarily be the case, as the story of AC and DC electricity

generation shows. The technological advantage of easily being able to distribute AC electricity over very long distances was able in a short time to displace the incumbent and dominant DC generation system to become itself the dominant electrical system. And as a dominant technology it has been in place for over 135 years.

Capital investment in technology is another factor in technology lock-in. For example, the building and commissioning of a nuclear power station takes up to 14 years and costs billions of pounds. It can be in operation for up to 40 years (Department for Business Enterprise & Regulatory Reform, 2008a), therefore such a technology is said to be locked-in due to its capital investment. A decision to purchase a particular machine or computer may lock the users in for the lifetime use of that particular technology. Therefore, for a sociotechnical system a transition from one regime to another, overcoming the barrier of technological lock-in is very important.

Arthur (1989, note 7, p. 26) articulates many examples whereby early adoption of a ‘winning’ technology that became locked-in, had the disadvantage of being of inferior design or quality, while other technology that ‘did not make it’ and became marginalised and locked-out, were of better design and quality. Some of the examples are: “*the narrow gauge of British railways (Kindleberger, 1983): the US colour television system: the 1950s programming language FORTRAN: and of course the QWERTY keyboard*” (Arthur, 1984; David, 1985; Hartwick, 1985). Another example quoted by Arthur (1989) was the dominance of light water reactors in nuclear power generation (Bupp and Derian, 1978; Cowan, 1987) that locked out gas-cooled reactors (Agnew, 1981). There are other locked-in barriers to overcome: they include financial barriers, market barriers cultural and behavioural barriers and information barriers (GEA 2012, Table 10.20, p. 732).

For the purposes of this research, to facilitate a transition it is important to identify how within an organisation change can occur. Those that facilitate the change are called ‘agents’. Hodgson (2006 pp. 16-17) explains that some institutions are more ‘agent sensitive’ than others. This means that institutions exhibit different degrees of sensitivity as to how those that operate within the institution can make changes. For some institutions, single agents can easily make change, for others it may take group consensus, while for others, it may not be possible to make changes at all. Therefore, for a transition pathway to be identified, firstly



the structure of a particular social network in the electrical regime has to be identified, then the ‘*agents*’ i.e. the people who have the ability to make change, will have to be identified, and thirdly the actions that they will have to do to implement change will have to be articulated. The prerequisite to finding a transition pathway for DC will be: understanding which components and which mechanisms maintain the lock-in (Allen et al., 2008; Unruh, 2000), how to break out (Farrell, 1985; Unruh, 2002), and what transition pathways will exist to facilitate the transition from AC to DC (Patwardhan et al., 2012; Verbong and Geels, 2007), or in the case of the 1.4 billion people not yet connected to electricity (GEA 2012), from their present lock-ins to the implementation of a DC system.

The literature has now provided the concepts of institution and multi-actor networks. Table 2.1 above was populated from the GEA report with organisations and groups. These groups can be looked at as the social networks that make up the sociotechnical electrical regime and the organisations are the institutions.

Figure 3.5 The networks of the electricity regime, arrows represent dialogue and knowledge transfer.

*actors* are called here **institutions**. For this research, the **actors** will be the actual people who make the decisions and operate within the institutions.

Therefore, to characterise the sociotechnical AC system, means to identify which technical and social networks make up the sociotechnical electrical regime, which different institutions make up each network, and who the actors are in each institution. (This was started by compiling Table 2.1 from the GEA (2012) and will culminate with Figure 3.6 below.) It should also include which actors facilitate interactions between the different social networks. This process is in essence identifying the elements of what Geels (2002, Section 1) calls a ‘*sociotechnical configuration*’. No institution operates in isolation therefore it is important to also identify and understand which outside organisations affect the operation of the institution we are trying to understand. It is also important to identify how the outputs from an institution, which are inputs to other institutions in a different social network, affect those institutions. The dialogues and knowledge transfer are the bi-directional arrows in figure 3.5 above.

### **3.3. What are the institutions? And how do they deal with change?**

It has been explained above (Section 3.2.6) that understanding and identifying an institution’s ‘*structuration*’ (Fuenfschilling and Truffer, 2014) is the starting point in understanding the ability of a transition to take place. Therefore, now that the social networks of the sociotechnical regime have been identified it is important to identify the institutions that make up each social network. It is important to remember the wider definition of institution as described by Hodgson (see Section 3.2.6 above) as opposed to the generalised understanding of an institution as being an organisation. In Chapter 2, Table 2.1 provided some of the institutions that exist within each social network. The narrative of the GEA report is again used to identify more of the institutions that are in each social network. Also used is empirical knowledge of the field of energy and transitions, publicly available reports etc.

### **3.3.1. Institutions in the research network**

The main research institutions that would affect the transition from AC voltage electrical system to a DC voltage electrical system in the UK include: The Institute of Engineering and Technology (IET), the Building Research Establishment (BRE), the British Standards Institute (BSI) and the National Physical Laboratory (NPL). Universities are a major source of research and together with energy and energy network companies are the backbone of research within the energy field. Whether it is an incubator company that seeks to develop a niche product or it is a multinational conglomerate that seeks to add new products to its portfolio, all companies' research and development programmes are institutions in the research network.

### **3.3.2. Institutions in the standards, codes, regulations, and obligations network**

Table 10.19 in the GEA (2012) sets out some of the control and regulatory instruments that a government can use in conjunction with energy policy: these include *appliance standards*, *building codes*, and *energy efficiency obligations and quotas*. Further to this, is the Code of Practice (CoP) and the Wiring Regulations BS 7671:2008- 2015 from the IET, and Health & Safety regulations. The British Standards Institute and the National Physical Laboratory are both instrumental in establishing standards. In appendix 2 there is a list of many standards that are geared to specific niche uses of DC voltage systems. Each looks at a specific usage such as for lighting in the office environment, for use in railways, ships, and cranes etc., however none of them are a comprehensive DC voltage standard for the built environment such as a domestic dwelling.

Both the IET and the IEEE recognise that there is a gap in availability of a DC standard for the home. The IET have decided that the pathway for a comprehensive grounded Standard is by firstly ratifying a CoP together with early take-up manufacturers of niche DC applications. The IEEE on the other hand has established a database of all known DC voltage standards that are pertinent to all niche applications, hence the compilation of the list in Appendix 2. It has its '*DC in the Home*' standard committee, who in July 2015 became officially established (see IEEE document IC13-005-03), whose route to a domestic DC Standard is to identify gaps in

the existing standards that mention DC voltage systems and go directly to forming a DC standard for the home.

### 3.3.3. Institutions in the energy policy network

Cluster 4, of the GEA incorporates chapters 22 to 25 and is dedicated to many aspects about how energy policy interacts with energy systems transformations. Energy policy is a key factor in energy transitions, just as much as systematic or technological changes (GEA 2012, Section 16.4, p. 1193).

*“Policy aimed at fostering energy transitions will need to involve a range of **government bodies** at various administrative levels in the analyzing of problems and the designing and implementing of policies. Government, therefore, will be one of the key actors in the transition process at **local, national, and international** levels.”* (GEA 2012, Section 25.10.3.2, p. 1790).

Therefore, the organisations that make up the institutions in the energy policy network include local, national and international government. Since each operates under different structuration they are therefore different distinct institutions in the policy network.

Table 10.19 in the GEA (2012), sets out some of the fiscal instruments and incentives that a government can use in conjunction with energy policy, these include **taxation** policy, including incentives that exempt or reduce the burden of taxation, and **subsidies** that include capital **grants** and subsidised **loans**. There are also public leadership programmes and education and information campaigns that inform the public about how they can help to fulfil the goals of the energy policy. These are therefore the channels of communication and points of dialogue between the energy policy network and other social networks in the electrical regime.

### 3.3.4. Institutions in the markets, suppliers & product manufacturers network

As has been explained above (Chapter 1), the model for the DC electrical system will be one that is of distributed form and can be off-grid. This means a change in the current model of the electricity supply away from the present centralised utilities. This does not mean that there will not be a place for the utilities. What is envisioned is a continual growth of what are called

energy service companies (ESCOs). “*ESCOs are private or public companies that can provide the technical, commercial, and financial services needed for energy efficiency projects*”, (GEA 2012, Section 16.3.4). For the supply of a DC electrical system, there would be an associated supply chain, which will include product *manufacturers, wholesalers, distributors, retailers, and house builders* who want the products, and electrical *installers* who will also maintain the system after installation. The development of a market in DC products will have to have the cooperation of everyone throughout the supply chain. Success will depend on knowledge transfer between policy makers, societal networks, education and the media. These are therefore the links between this social network and many others.

### **3.3.5. Institutions in the finance and investment network**

The International Energy Agency (International Energy Agency, 2014) estimates that the accumulative investment in energy supply and efficiencies required by 2035 globally will be between \$48 and \$53 Trillion, of which \$2 Trillion will be needed in Europe just for the electricity sector. Much of the money needed in the developing world comes from the World Bank. In the developed world investment money may come internally from *generated profits*, from the *money markets*, from *banks* or from *governments*. Traditionally, for homeowners to finance a microgeneration system on their home, the money came from *savings*, a *loan from a bank*, a *government grant* or a combination of these. (The words italicised indicate the institutions in the finance and investment network.) Personal savings have been included as an institution, as not only are there reasons why someone saves, and rules and regulations surrounding personal savings schemes, there are also the cultural and social norms around a person's decisions to use personal wealth for a microgeneration project. In the UK the government set up the first Green Investment Bank (Green Investment Bank, 2014) in the world, to finance things like renewable energy systems. Institutions in this network not only finance the end installation of systems, but are also involved in financing research and development. Therefore, via government this network is connected to the policy network, via property owners to the end user network, and via R&D to the research network.

### **3.3.6. Institutions in the societal network**

There are many organisations that through their outputs can influence the shape of the electrical regime, and therefore any transition to DC voltage systems. Some of these are the same as those in the nuclear safety regime shown in Figure 14.18 in the GEA report. They include: the media, international organisations, NGOs and professional networks. Many of the international organisations can be found in Annex 1 page 1810 of the GEA (2012).

### **3.3.7. Users network**

The label “Users” is used very loosely, as besides the consumers, users must also include the electricians, technicians, and engineers that install and maintain the system but are not yet themselves consumers of DC electricity. They are included as users because; before they can certify the system it has to work properly and safely for them. Their interaction with the DC system has to be as if they are consumers to be able to test the system’s operability.

### **3.3.8. Dialogue and knowledge transfer (education)**

Dialogue is about informing, educating, and bringing diverse opinions into the decision making process (GEA 2012, Section 25.10.2.4), it also provides a pathway for receiving feedback. It is not only important within a vertical approach to a single concept, it is also very important within a framework for implementing a cross disciplinary horizontal approach, such as the transition of the AC electrical system to a distributed DC topology. Dialogue is important in developing and institutionalising the ability for transitions to take place. Education is about knowledge transfer and exchange, which is important for a successful dialogue to take place. Developing and keeping a focus on transformative change, however, cannot succeed in the absence of broad-based support, continuous dialogue, and a long-term, systems-based approach to change. The arrows in Figure 3.5 represent the dialogue, knowledge transfer, outputs and inputs, and feedback loops that exist between the institutional actors of the different technical and social networks.

Governments are crucial actors when transitions in the energy regime are to take place. Adopting a systems approach and a multi-goal perspective will require dialogues across ministries and the creation of inter-ministerial teams for policy integration and coordination.

Capacities for dialogue and policy coordination must therefore exist or be created. Access to knowledge and information – and the capacity to use such inputs – are critical in making choices about energy transitions, whether at the level of individual actors, communities, or national governments (GEA 2012, Section 25.10.3.2).

### 3.3.9. The institutions that makeup the social networks of the electrical regime

Bearing in mind Hodgson's (2006) definition (Section 3.2.6 above), that an institution is more than just an organisation Figure 3.6 was populated with the different institutions for each of the networks in the electrical regime. The institutions and networks were initially derived from the GEA (2012) that was used to populate Table 2.1 above. Further to this, from the literature search more was added. This is not an exhaustive list but rather a representative list of institutions.

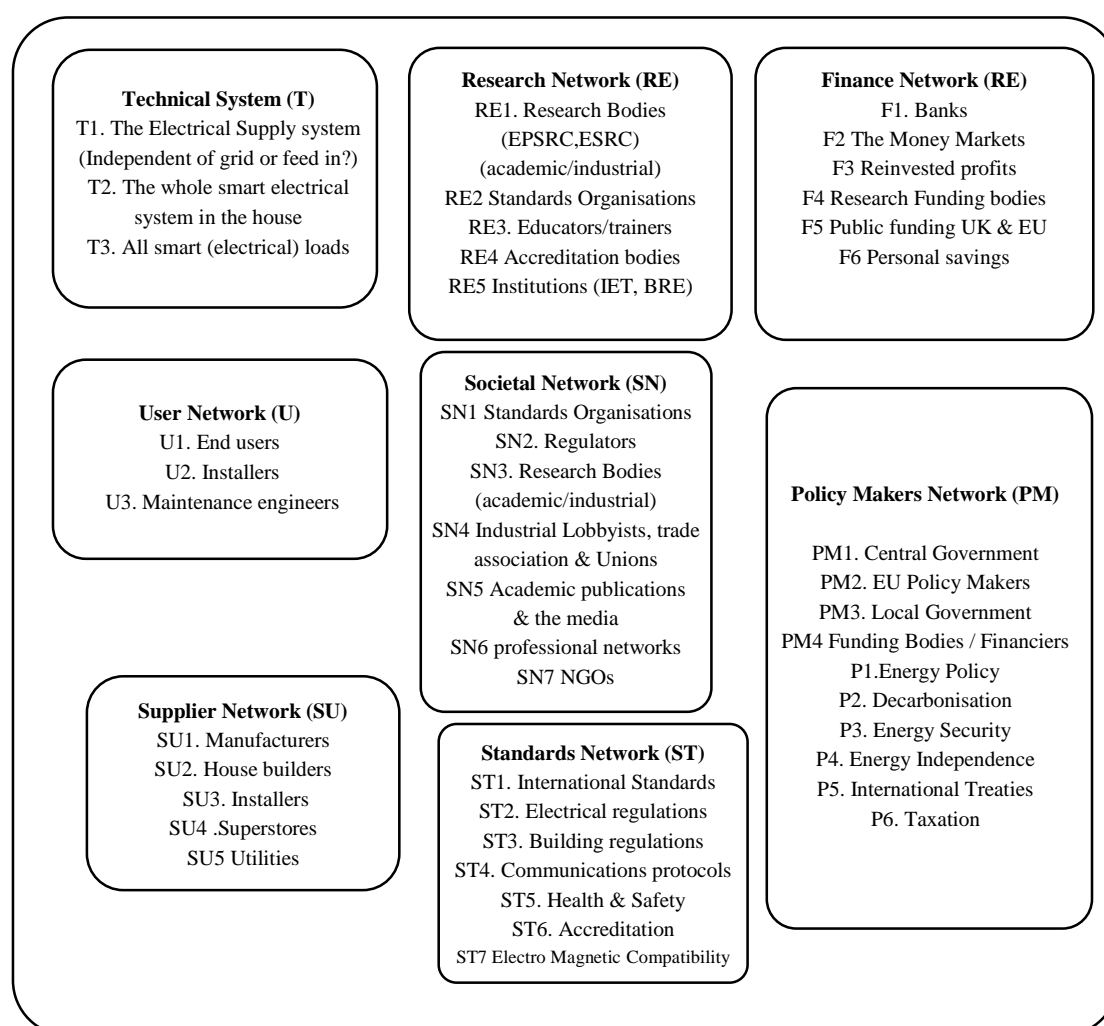


Figure 3.6 The institutions that make up the technical and social networks in the electricity regime.

### **3.4. Some weakness and knowledge gaps within the MLP theory**

During this literature search of the MLP theory on TTs, some gaps in the research and knowledge base were identified and are now discussed below. Further to this, weaknesses in the MLP theory were identified, which highlighted a conundrum within sustainable energy transitions (Section 3.5). Understanding the conundrum and how to circumvent it, will be crucial for a successful transition to DC voltage systems.

#### **3.4.1. The sociotechnical landscape**

Geels provides a response to criticism of his MLP approach to modelling sociotechnical systems in his paper (2011, Section 3.6). He states the following:

*“The landscape level has been criticized for being a residual analytical category, a kind of ‘garbage can’ concept that accounts for many kinds of contextual influences. This is a fair criticism, which can be made productive by reformulating it as a need for more theorization.”*

He suggests two developments that need to be undertaken;

*Firstly, “the landscape concept can be made more dynamic”. Secondly, “more attention could be paid to landscape developments that help stabilize existing regimes.”*

Developing a further and more detailed understanding of the landscape, is identified as a gap in the literature. This research will seek to develop an understanding of the ‘*dynamics*’ of the electrical energy landscape to see if its different components are fixed variables outside the control of the system actors themselves, or are a constraint developed and imposed by the institutional actors, and therefore more easily changeable than had been previously understood. (See Section 3.5.3 below)



### 3.4.2. The regimes

The GEA report (2012, p. 1178) identifies a knowledge gap in the detailed identification and analysis of the sociotechnical regimes of case studies found in the sociotechnical academic literature, including understanding how they operate. It is envisioned that the process of transition path development will focus on how the regime actors work within their own social network and between different networks. A further discussion of the regime is undertaken in Section 3.5.1 below.

### 3.4.3. Institutional structuration – institutionalisation

The GEA (2012, p. 1193) in Section 16.4.1 quotes the following from Smith & Stirling (2010):

*“Institutionalization is often given the least consideration in transition management literature, despite the fact that it is the most important factor in transition management. Institutionalization involves the mobilization of serious selection pressures against the incumbent regime, and the redirection of vast institutional, economic, and political commitments into promising niches along certain feasible pathways. This is the point at which serious commitments are needed, to the extent that the incumbent regime suffers and is undermined as a result. This step is difficult politically as well as economically.”*

It also states in Section 25.10.1.1 that,

*“Understanding these informal institutions and learning to work with and around them in a given context are important first steps in an energy transition process”.*

This research therefore identifies institutionalisation as being a gap in the transition management literature. In the context of this research, institutionalisation means making the niche innovation, and the distributed DC electrical systems, become inculcated into the norms of the incumbent institutions that make up the social networks of the AC electrical regime. To do this it is incumbent to understand the structures, mechanisms and pathways for change within and without the organisation, this is what this research defined as institutional structuration (see Definitions at the beginning of this thesis). For further uses of the label institutional structuration see the following (Lammers, 2003; Landry and Amara, 1998; Scott, 2000),

### 3.5. A conundrum within the MLP on sociotechnical transitions

Lockwood (2013, p. 15) highlights the following question:

*“The recent history of electricity distribution network policy and the slow pace of the development of smart grids **raises the question** of why, while major landscape developments appear to have opened up new niches for innovation, they have not destabilised the regime?”*

His discussion is around the slow uptake of smart-grid technology, which holds up the ability of renewables to feed into the grid, thus hampering the pace of growth of renewable or low carbon technologies. In a similar vein Geels (2014b) discusses the resistance to transitioning to a low-carbon society. The focus of his paper is a discussion about the failure of the low carbon transition to take place, and the resistance and expansion of the fossil fuel and nuclear regimes, which he highlights as being due to the interaction between the incumbent regimes (Markets) and those in power (politicians). Geels (2014, p. 25) advocates that the solution lies in the need to focus on understanding and enacting the destabilisation of and causing a decline in, the fossil fuels-based regime. He states that the incumbent fuel regimes i.e. coal, gas and nuclear show a strong resistance and resilience in the face of policy to reduce carbon emissions. He sees the barrier to this destabilisation as being the active resistance of the fossil fuel regime actors, who are leveraging pressure on the policymakers. This resistance is not viewed as active resistance against change, but as the politicians making policy that keeps the status quo for reasons of self-interest. Policy makers and business tend to form close alliances because of mutual dependencies. Businesses need the stability that a stable government offers in order to operate, and governments need business to provide employment, economic growth and its fiscal needs (Geels 2014, p 26).

On one hand the UK, with its 2008 Climate Change Act, was the first to enshrine in law its goal for reductions in carbon emissions, which shows the public commitments to deal with climate change. While at the same time advocating ‘clean’ coal and nuclear to the detriment of greener sources of energy, and the further deployment of smart grids and smart meter technology. Furthermore, *“relative electricity production from renewable sources went up from 4.3% in 2005 to 11.3% in 2012. However overall carbon emissions from electricity generation have not improved between 2000 and 2012 (Figure 2), because of increased coal use, especially between 1999–2006 and 2010–2012 (Figure 3)”* (Geels, 2014b, p. 24).

There is therefore what this research calls: “A conundrum within the MLP on sociotechnical transitions” which will be called “**The Conundrum**”. The UK’s energy system will be used as an example to contextualise ‘The Conundrum’ as follows: how is it possible that there exist scenarios whereby windows of opportunity have opened in the energy landscape, and allowed many niche low carbon technologies to develop, yet the incumbent regime keeps its power and is able to deflect any destabilisation from the niche? Is it possible that distributed DC electricity systems may overcome this conundrum?

To attempt to look into The Conundrum, there is a need to untangle the different forces at play, and to understand and map out in more detail, the regime and landscape levels of the MLP with respect to the energy and electricity systems.

### **3.5.1. Understanding the regime level within the MLP model**

In any research it is important to define the framing, and to identify the system and its components so that ambiguities do not arise between different understandings of the same concepts. In this case understanding and defining the parameters of the system under analysis and what the regime is, is very important. From Geels’s diagram of the MLP, Figure 3.2 above, the sociotechnical regime is depicted in a plane, with two-dimensional regimes existing within this plane as discs. With this conventional model the regime comprises many concepts existing in the same dimension. In his paper Geels (2014b) ascribes many descriptions to the regime: incumbent regimes, existing regimes, the fossil fuel based regime, the coal regime, the nuclear regime, regime actors, regime level alliances, vested regime interests, existing regime actors, and incumbent regime actors, see Table 3.2 below. All the activities of the technology, actors, norms and policy all exist in the same plane.

This type of analysis is useful when the goal is to use the MLP theory to understand a generalised transition from a theoretical point of view. However, is it helpful, when trying to comprehend the dynamics of a specific detailed transition? For example, the ability or otherwise of low carbon electricity generation, to substitute the incumbent fuel regime, i.e. ‘The Conundrum’. Geels (2014b), is dealing with electricity generation, what is not clear is, do all these regimes exist in a singular system with a defined landscape or are they components of different sociotechnical systems?

To understand how ambiguities can exist, the *system* under analysis will be parametrised as the process of electrical generation, with the technical aspects being the plant used to generate the electricity. This plant has many inputs and one output Figure 3.7.

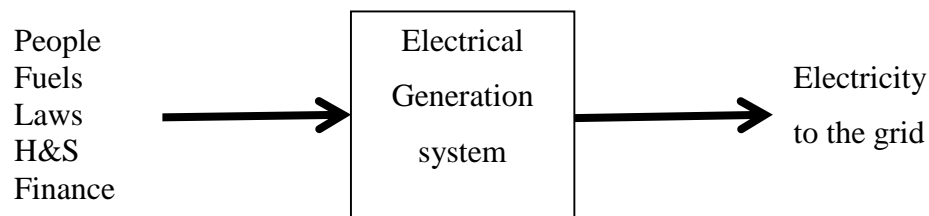


Figure 3.7 A very simplified model for the electrical system.

In the simple conventional model for the MLP, Geels defines these inputs as existing at the “sociotechnical regime” level, which is also described as the meso-level which is also named “patchwork of regimes”. Some of the inputs to the electrical generation system are: (1) the fuels used to generate the electricity, (2) laws, like health and safety, emissions etc, (3) operational parameters that include codes of practice, and national and international standards, (4) the workforce and all associated rules etc., (5) the owners or shareholders, (6) depending on the financial position of the company finance, which may include banks, and bond holders, as well as others. When Geels describes a “patchwork of regimes” as existing at the “sociotechnical regime” level, are these six groups of inputs the ‘multi-actor networks’ which are subsets within the regime, but not the actual regime itself, (as in Figure 3.3 above), or is each itself defined in association with the word ‘regime’? Table 3.2 below shows that the terminology used by Geels (2014) when describing the inputs and outputs of the electricity generation system are all associated with the term ‘regime’.

Table 3.2 Different usage of the word ‘regime’ found in Geels (2014b).

	<b>Different usage of the word ‘regime’</b>	<b>Either synonymous with or could mean</b>
1	Sociotechnical regime	
2	Existing regime	The coal regime, nuclear regime
3	Regime actors	Sociotechnical regime actors
4	The coal regime, nuclear regime	Incumbent regime, existing regime
5	Incumbent regime	The coal regime, nuclear regime
6	Fossil fuel based regime	The coal regime
7	Regime level alliance	At the sociotechnical regime level
8	Incumbent industrial regime	Sociotechnical regime
9	Regime resistance	Sociotechnical regime
10	Vested regime interests	The coal regime, nuclear regime
11	Existing regime actors	Actors in the coal regime, nuclear regime
12	Incumbent regime actors	Actors in the coal regime, nuclear regime

To understand how decisions are made within an institution, an example of a political decision to support off-shore wind farms is used. This political decision resulted in the decision to create the Green Bank to help provide finance to companies within the green energy field. An actor within a renewables company decides to take up the opportunity to borrow from the Green Bank and invest in an off-shore wind farm. Starting from the decision (the bottom line of Table 3.3), we have (7) the decision, (6) the decision making procedures/processes of the company, (5) the decision makers/actors, company owner (4) who operate within and on behalf of the Company, (3) that operates within the wind energy sector, (2) that is a single type of generation within the electricity generation sector (1) which is a single type of output of the energy generation sector. There are therefore seven levels or ramifications to a decision to invest into a new windfarm.

Table 3.3 The seven levels from decision to the energy sector affected by the decision.

Level	Ramifications of a decision	Conventional description	New description
1	Energy sector	System under research	The Energy system
2	Electricity sector	Electricity regime	Electricity regime
3	Wind energy sector	Wind energy regime	Societal networks in the regime
4	The Company	Institution	Institution
5	Decision maker	Regime actor	Actor – is context sensitive
6	The decision making process	Structure part of structuration	Structure
7	The decision	Action part of structuration	Action

While it is possible to break up a process into seven levels, how are these levels described within the conventional MLP model? Level six and seven have been labelled, *structuration* (see Section 3.2.6 above), level four is the institution and level one is the system under research. However, levels two, three and five, which are points of entry and exit to and from the decision to borrow money to make the wind farm, are in fact just labelled ‘regime’. They may also exist in different guises as the system under discussion, within the niche or within different parts of the regime. People play multiple roles and can therefore exist in multiple levels. As Table 3.2 shows the use of the word regime can be oversubscribed and can lead to confusion especially when dealing with a complex system. Therefore, the regime should not be looked at as existing in a two-dimensional plane, as in the conventional MLP model, but rather as existing in a multi-dimensional plane.

The model now shows the actions in the electrical sociotechnical system as taking place on the fifth level below the regime, as outputs from the structure within institutions. This is depicted as a three-dimensional nested structure in Figure 3.8 below, which means that the patchwork within the electricity regime exists like a column with a depth of five generalised levels, and not a two dimensional disk as depicted by Geels in figure 3.2 above.

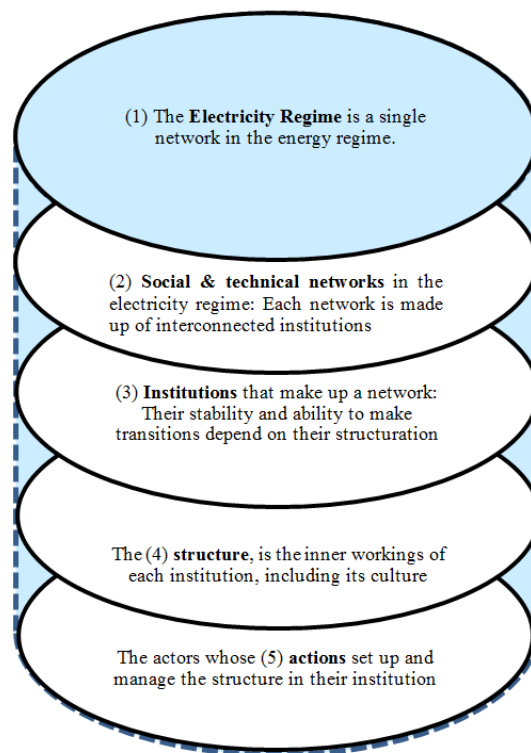


Figure 3.8 The five levels within the 3-dimensional electricity regime.

How does this new model of the regime help to better understand the regime and will it help to formulise a solution to ‘The Conundrum’?

### 3.5.2. Giving new meaning to the ‘patchwork of regimes’

By definition some of the networks that comprise the sociotechnical regime will be technical while some will be social. Therefore, it is preferred to describe these networks as either being ‘*technical networks*’ or ‘*social networks*’ of the sociotechnical regime, rather than just ‘multi-actor networks’ as described by Geels (2002). This label ‘*social networks*’ is different from what Verbong & Geels (2007, p. 1026) describe as different networks of people who are the “*organisations capital*” within the institutional framework of the sociotechnical system, their Figure 6. Here ‘*social networks*’ are used in a wider context to include any network that is not the actual technical part of the sociotechnical system. Therefore, for the energy system, ‘*Energy policy*’, ‘*fiscal policy*’, or the actual ‘*laws and regulations*’ themselves will each be labelled a separate social network, since they are all inputs to the sociotechnical system. What is gained by this is that, when doing sociotechnical analysis, it is important to frame the

networks with respect to their aspect that is important to the analysis being undertaken. Here they are single instances of inputs to the electricity system. However, within a different analytical context, each could be the actual sociotechnical system itself. Furthermore, an instance of each technical or social network will be framed as an ‘*institution*’.

What components of the system are ascribed to technical networks and which are ascribed to a social network, is not pre-defined, but are defined by how the researcher frames them. Technical plant and inanimate inputs like fuel are assigned to a technical network (red) and people, their norms, outputs, and policy are ascribed to a social network (blue). For example, if the system under analysis is the **energy system**, then ‘*types of energy produced*’ will be a ‘technical network’, and ‘*electricity*’ will be a single ‘institution’ (green) within this technical network, and ‘coal’ will be an institution in the ‘*primary fuels*’ technical network. Within this ‘primary fuels’ technical network may also be low carbon fuels like wind or solar, Figure 3.9.

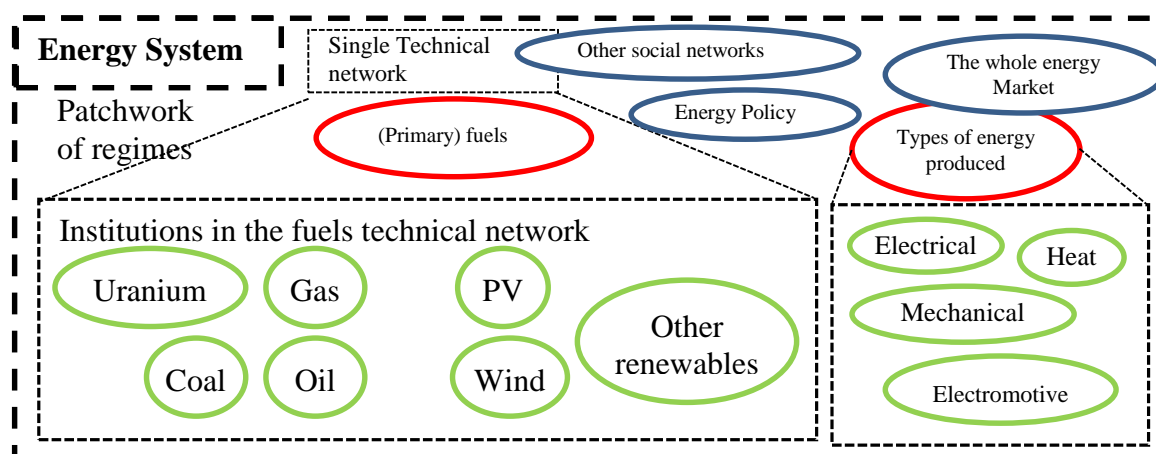


Figure 3.9 The technical and social networks in the regime level of the energy system.

However, if only the **electricity system** is under analysis, then a single instance of a technical network in the regime can be fossil fuels and other low carbon generation, with coal now being an instance of a single ‘institution’ within the fossil fuels technical regime and wind or solar as being single instances of the ‘low carbon fuels’ technical regime network’, Figure 3.10 below.



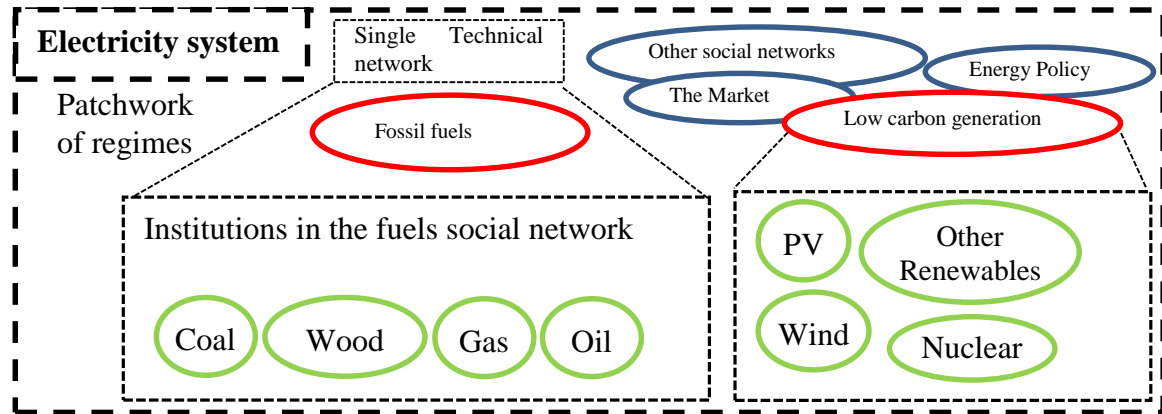


Figure 3.10 The technical and social networks in the regime of the electricity system.

Therefore, framing contextualises where coal sits within the sociotechnical system. Depending on the chosen ‘*unit of analysis*’, and/or the framing of the research question, renewables and coal will sit in a different place within the sociotechnical analysis and have a different significance with regard to other components within the research. In the energy system, if the goal is to reduce the carbon emissions, as they are in the same technical network they are not in direct competition, i.e. as long as the overall emissions are reduced policy can include an increase in coal and a reduction in oil to the detriment of renewables. While in the electricity system, they are in different networks and therefore in direct competition, which means that a policy that increases coal to the detriment of renewables will fail to reduce the overall carbon emissions. This analysis is not dissimilar to Berkhout et al. (2004, p. 54), who argue that the electricity domain could be looked at on the level of primary fuels or the entire system. They therefore question “*how these conceptual levels should be applied empirically*” and “*what looks like a regime shift at one level may be viewed as an incremental change in inputs for a wider regime at another level.*” (Geels and Schot, 2007). For example, Table 3.4 shows how depending on the system under analysis, coal the fossil fuel central to Geels’ 2014 paper, takes on a different significance.

Table 3.4 Coal as framed within different systems under analysis.

System under analysis	What is coal?
The coal system	Coal is the sociotechnical <b>system</b>
Fossil fuels system (FFS)	Coal is a <b>technical network</b> within the regime level of the FFS
The energy system	Coal is an <b>institution</b> in the primary fuels technical network within the regime level of the energy system
The electricity system	Coal is an <b>institution</b> in the fossil fuels technical network within the regime level of the electricity system

On the surface, this exercise seems to be about semantics and seems to only add complexity. However, when one looks at coal as either being a single technical network in a larger set of other technical networks, or if one is delving deeper to understand the institutional structuration of coal as a single instance of a type of fuel, one will have to take into consideration how coal's structuration interacts with or competes with other types of institutions or technical networks. When coal is framed as a technical network in the fossil fuel sociotechnical regime, the effects the landscape pressures and any niche innovations will have on it, will be different than when coal is a single instance of an institution within the fossil fuels network of the *electricity* system and will have a different dynamic as an instance of an institution within the primary fuels network of the *energy* system. In essence when looking to understand the sociotechnical transition process from coal to a low carbon substitute, as Geels (2014) does, one has to understand the significance and weight of coal compared to other types of fuels, either on the institutional level, or on the level as a technical network of the regime. Is it a straight comparison with other fossil fuels i.e. gas? Is it a comparison with renewables or nuclear? Or is it purely coal's CO<sub>2</sub> emissions characteristics that are under discussion?

To contextualise how institutional networks and their structuration exist within the regime, this research showed that there are five structural levels within the sociotechnical electricity regime, Figure 3.8. This complexity shows the limitations in the conventional two-dimensional MLP model. Given the three-dimensional complexity of the regime level of the MLP, what more can be understood about the landscape level beyond that provided by the conventional model?

### 3.5.3. Understanding the dynamics of the landscape in the MLP theory

To summarise what is known about the landscape: Geels (2002) explains that the landscape “contains a set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems. The landscape is an **external structure or context for interactions of actors.**” During the early phase of the MLP model, papers on this subject characterised the sociotechnical landscape as being in a stable state or as a very slow moving state, and has been compared to the physical ecological landscape (Van Driel and Schot, 2005). Geels (2007) describes the content of the landscape “...they form an **external context** that actors cannot influence in the short run.”, Geels’ (2007) examples of landscape pressures that came from outside the ‘shipping transport system’ were political revolutions (1848), and the Irish potato famine (1845 -1849) that opened up opportunities in the trans-Atlantic passenger market. However, the description of the landscape was criticised as being a “*residual analytical category*” (Geels, 2011, Section 3.6). The later description of the landscape level differentiates three types of landscape dynamics (Geels, 2011): “(1) factors that **do not change** (or that change very slowly), such as physical climate, (2) rapid **external shocks**, such as wars or oil price fluctuations, and (3) **long-term changes** in a certain direction (trend-like patterns), such as “demographical changes.”. It was due to criticism that Geels (2011) stated that regarding criticism of the concept of ‘landscape’, firstly that “the landscape concept can be made more dynamic.” Secondly, it was stated that “more attention could be paid to landscape developments that help stabilise existing regimes.” (This is a gap in the knowledgebase, identified in Section 3.4.1).

The MLP theory therefore still looks at the landscape as being ‘external’, (exogenous (Geels 2014, p. 23)) either slow moving or reacting to a step change input, but has thus far not included any actions of the actors in the regime as being key to establishing what the landscape pressures are. The questions now are, given this conventional MLP understanding of the landscape, what is the extent of its externality to the system under analysis and what is its time frame for the speed of change?

The UK energy system exists within a mature production and distribution system, stabilised by many locked-in mechanisms, where continuity of energy supply is taken for granted by most consumers. This research puts forward the hypothesis that whatever the named landscape pressure may be, they all stem from one overarching pressure which is ‘*continuity of energy supply*’, which is energy security (House of Lords, 2016, Section 2), or the ‘*keeping the lights on*’ part of the UK energy trilemma (Department of Energy and Climate Change, 2014a), and that the other landscape pressures are associated with achieving this continuity of supply. While ‘keeping the lights on, i.e. ‘continuity of energy supply’ is the overarching landscape pressure it is still dependent on other landscape pressures such as a continuing availability of fossil fuels, supply chain resilience to sudden changes like natural disasters, terrorism or war, and the consumer’s ability to pay for the electricity without being in “fuel poverty”. It is also postulated that government energy policy sets the framework of the energy system so that the landscape pressures will be pertinent within their particular country, i.e. politics ‘*mediates*’ (Kraemer et al., 2001) or prioritises between different possibilities when formulating energy policy. The 2007 White Paper on Energy (Department of Trade and Industry, 2007) added energy security and energy affordability to the energy policy agenda.

In Europe the reduction of carbon emissions is seen as one of the most important landscape pressures on the energy system. This manifests itself through the many EU directives including EU Emissions Trading System (EU ETS), Renewable Energy Directive, Energy Efficiency Directive (2012), New car and van CO<sub>2</sub> targets, etc. Whereas it is said that, since the USA which is a major industrialised nation did not sign up to the Kyoto Agreement, for them (excluding California) the pressure for carbon emissions reduction is much less, as will be explained. Much of the UK’s policy for electrical energy including that for low carbon renewable generation is underpinned by Carbon Emissions Obligations (CEO) (Department of Energy and Climate Change, 2013), which was replaced in 2015 by CEO2, which runs until 31<sup>st</sup> March 2017 (Ofgem, 2016).

The Kyoto Agreement did not place strong restrictions on the emissions of emerging economies like China, India and Brazil. The reason for this was that emerging economies are driven by the need for economic (GDP) growth, which is the means to increase people’s

living standards by taking them out of poverty. Therefore, these three countries, as well as many others, forged ahead without having CO<sub>2</sub> reduction underpinning their energy policy.

The Global Energy Challenge of ‘universal access’ to electricity mentioned in the GEA (2012), is only pertinent to the countries that have a section of population that at this time have no electricity supply. This is, therefore, a landscape pressure specifically for these countries.

Since 2005 there has been a crisis between Ukraine and Russia (Geels, 2014b, p. 30) and natural gas piped to many Eastern European countries via Ukraine has been temporarily stopped. Although Russia has claimed it had no political agenda and that this crisis was purely economic, due to monies owed to it by Ukraine, the knock-on effect to Western Europe and its dependence on Russian energy leaves it very vulnerable. As an aftermath of the second incident between the Ukraine and Russia, in January 2009, Energy Ministers across Europe began thinking about what the European Community can do, on a pan European level, to reduce its reliance on Russian natural gas. European energy security has come more to the forefront of energy policy in the last few years. Yet despite this change in EU energy policy in 2015 Europe and the UK are still reliant on primary fuels from Russia. For example, in 2013 the UK imported 38.8% of its coal from Russia (Digest of UK Energy Statistics 2014 p 133). Although the UK by 2014 was not importing gas from Russia, and thus seems to be well insulated against the Russia-Ukraine situation, “...however, due to GB’s interconnectivity with Continental European markets, disruption in mainland Europe could have consequences for the UK market.” (Department of Energy and Climate Change and Ofgem, 2014, p. 48), i.e. the continual effects on the energy markets have been exacerbated by the ongoing separatist conflict in Ukraine (Goldthau and Boersma, 2014).

Furthermore, Gazprom had an intention to terminate its gas exports to Europe via Ukraine by 2019, by opening a new pipeline to Italy via Turkey and Greece (Roberts, 2015). This means that two of the most geopolitically sensitive countries, Greece within the EU and Turkey a long time applicant to join the EU will, if this project ever happens, have the upper political hand that could potentially weaken the whole EU and could provide a political block of Russia, Turkey and Greece. It is therefore time for energy policy scholars to re-evaluate the meaning of Energy Security from that of securing via long term contracts energy supplies

(Wicks, 2009), to a meaning that is closely coupled with energy independence as advocated by the USA.

In the USA, the Bush administration focused on the strong connection between the market price of oil, the economy, and energy security (National Energy Policy Development Group, 2001), and therefore used its energy policy via Executive Orders 13211 and 13212 to achieve its broad policy objective of achieving national security by means of energy independence (Forbis, 2014, p. 160). Thus in the USA energy security with energy independence was seen as underpinning USA energy policy (National Energy Policy Development Group, 2001). The USA have tried for years to become independent of imported oil, this is not because it fears peak oil but rather it has placed energy security and energy independence at the forefront of its energy and economic policies. This strategy has been continued during the Obama administration and was (in 2014) called the All-Of-The-Above Energy Strategy (Council of Economic Advisers, 2014). The term 'peak oil' was not in the National Energy Policy Report (National Energy Policy Development Group, 2001), what was, was "*world oil price volatility*". In the CEA's report the Obama Administration's goal continues to be to "*...reduce the vulnerability of the U.S. economy to oil price shocks stemming from international supply disruptions*".

The greater the ability of a country to be less reliant on oil and therefore its volatile price, the less of an external pressure the price of oil and peak oil is on its energy system. Furthermore one of the examples given in the literature as a landscape pressure was the 1973 oil crisis (Verbong and Geels, 2007, p. 1027), however only the countries that were dependant on oil were adversely affected. What were called "third world countries" in 1973, were very much less impacted as they were very much less dependent on oil. However, the availability of oil to produce electricity and therefore peak oil was not and is not a landscape pressure on the *electrical systems* of countries that do not use oil to produce electricity. Oil will, though, be a landscape pressure on the *energy system* as it is used to make petrol for all types of transportation.

It can be concluded from this discussion and from extensive reading of relevant literature and reports, especially the GEA (2012) report, that there are at least eight identifiable landscape

pressures on the general energy system. A different combination from this list underpins the energy policy of different countries.

1. Peak Oil
2. Universal access
3. The Carbon footprint
4. Fuel poverty
5. Energy security
6. Energy independence
7. GDP growth
8. Economic stability

Furthermore, from the above discussion it can be derived that many governments have a central core policy that governs their energy policy. This has been designated the ‘main’ landscape pressure on the energy system. However like the UK’s trilemma, there are other policies that are priorities that form part of the overall energy policy that surround the core policy, these energy priorities are designated as ‘secondary’ landscape pressures. This research has further identified from the GEA (2012) energy policy priorities that are only pertinent primarily to some countries and not to others, it has therefore designated them as ‘other’ landscape pressures in the countries that they are not part of their energy priorities.

Table 3.5 A simplified presentation of different countries landscape pressures.

<i>Continuity of energy supply applies to all countries</i>				
<b>Country</b>	<b>Main Landscape pressure</b>	<b>Secondary landscape pressure</b>	<b>Other landscape pressure</b>	<b>Other landscape pressure</b>
Europe UK	Carbon reduction	Energy security & Independence	Peak oil equates to price of oil	Fuel poverty
China, India Brazil	GDP growth	Fuel poverty	Universal access	Carbon reduction
USA	Energy security and energy independence	Peak oil equates to price of oil with economic stability	Carbon reduction	Fuel poverty
Developing nations	Access to fuel	GDP growth	Peak oil equates to price of oil	Fuel poverty

Furthermore, from the above discussion it can be derived that many governments have a central core policy that governs their energy policy. This has been designated the 'main' landscape pressure on the energy system. However like the UK's trilemma, there are other policies that are priorities that form part of the overall energy policy that surround the core policy, these energy priorities are designated as 'secondary' landscape pressures. This research has further identified from the GEA (2012) energy policy priorities that are only pertinent primarily to some countries and not to others, it has therefore designated them as 'other' landscape pressures in the countries that they are not part of their energy priorities.

Table 3.5 A simplified presentation of different countries landscape pressures seeks to show how for the late 2000s in different countries their energy policy was driven by different landscape pressures. This is a simplified look at a complicated subject, yet it is not hard to see that some countries have different energy policy goals that therefore impose a specific set of landscape pressures on their own energy system. What may be seen as a primary landscape pressure for a developing nation, is seen by a developed nation as a secondary pressure. It is therefore postulated that, it is the internal actors, the policy makers, that have great influence to mediate and prioritise which landscape pressures will operate on their energy system. This does not negate the adverse effects of world events like war and commodity prices, short term external shocks that do have their impacts (Geels 2011), but rather that from the point of view of ongoing energy policy, energy policy goals are not prioritised to primarily deal with these particular external shock events.

The estimated time from preparation and permitting, to decommissioning of a 'generic' nuclear power station is given as 54 years (Department for Business Enterprise & Regulatory Reform, 2008a, Chart 2). This type of power generation technology, given capital investment and average longevity of the project, and its importance in the UK as base-load generation, can be envisioned as being a locked-in technical system. However in Germany, after the Fukushima nuclear disaster, the government decided to close down and phase out all their nuclear powered power stations by 2022, something that a year earlier they had been against (BBC News, 2011). This was not dictated by technical obsolescence, but by a political decision. By removing nuclear generation, this changed the dynamics of the types of fuels used to generate electricity and opened up opportunities for low carbon generation to fill the gap. However, in the UK despite the 2003 white paper negating nuclear as a future means of



electricity generation, the Prime Minister, Tony Blair put it back on the agenda. Both these governmental decisions show that dynamics in the energy field can be changed relatively quickly if politicians choose to do so.

This research therefore postulates that it is the decision makers within the energy policy field that mediate the priorities of the energy policy, thus determining what are the landscape pressures their policy is aimed at mitigating. The ramifications of this are that there is a need for a rethink of how transition scholars view the concept of ‘sociotechnical landscape’. It may not be as slow moving, or as external as had previously been thought.

This understanding of what is taking place within the regime and how the landscape pressures are imposed on the electricity system, cannot itself answer The Conundrum. However, after the primary data for this research was gathered, a tentative explanation is given.

#### **3.5.4. The importance of the carbon debate within electrical generation**

This example conundrum is predicated on the fact that the UK Government has a policy of carbon emissions reductions, yet at the same time advocates coal as a means of electricity generation. It is important to understand the development of what is called the ‘carbon debate’ to contextualise UK energy policy and to understand the motivations for shifts in this policy.

It has been a long journey from the first report to the Club of Rome, entitled “The Limits to Growth” (Meadows and Club of Rome., 1972) to the implementation in 2015 within the UK of a decarbonisation strategy for the electricity generation system. To understand why fossil fuels are still dominant within the UK’s electricity generation system one has to delve into this 43-year journey.

From 1972 onwards, there have been two ideological camps, one advocating the importance of the reduction of carbon emissions as being essential to the ‘Global Warming’ issue while others who challenge the very idea that ‘Global Warming’ exists or that there is a need to deal with it via carbon emissions reductions. The debate raged as to whether it is manmade or a natural cycle like El Niño and La Niña. One side of the argument believes in the need for strong interventionist policies while the other side wants the opposite, a full market solution.

In 1972 the vocal minority were those who were advocating the need to do something about 'global warming' while the majority were not convinced. In 2015 the pendulum has swung in the opposite direction, where it is the vocal minority who 'deny' or 'oppose' the whole climate change agenda. There has been a huge semantic argument over the decades as to the terminology of 'climate change'. Since this discussion is about generating electricity through low carbon means, the focus will be on the forces active within the carbon reduction debate.

Each side of the debate uses science, the media, and strong lobbying techniques to advocate their positions. Over the years the 'Global Warming' advocates moved from operating as niche advocates to becoming dominant within international politics, and the international community via NGOs and the United Nations. Politicians in every nation-state have international pressure to do something about what is now called 'climate change'. Part of dealing with climate change is the reduction of carbon emissions. Whether the politicians of any single country engage or not, only effects how they deal with it, but 'climate change' is definitely a landscape pressure on all political systems, regardless of how they deal with it. The only difference will be the extent of the pressure from within their country and from the international community. As discussed above, a major country like the USA has the ability to not sign up to any international agreements on climate change, which reduces the external pressure, but still has to deal with the pressure from its citizens. The extent that any political system will engage with this debate will depend on the strength and political persuasion of the Government and the internal and external pressures.

Politicians and especially energy policy makers therefore receive different, and in many cases conflicting information when seeking advice and knowledge that will help them formulate policy. The ramifications of a particular policy do not only have direct impact within the field that it is directed, but also has secondary effects beyond those confines. In our example if the carbon reduction policy is seen as having a positive effect on the country, the government will receive public acclaim. However as soon as someone connects the increase in cost for electricity to the increase in fuel poverty, and then directly connects it to the UK Government's 'green' initiatives, the Government can receive a public backlash (Gosden, 2015). A weak government coupled with a weak economy and focusing on the next election,

where it seeks to strengthen its power, looks for ways to shift its policy to alleviate these other more pressing landscape pressures.

### **3.5.5. Windows of opportunity –A further discussion of the MLP theory**

For change to occur in any stable operational system, there needs to be an input function that is able to disturb the equilibrium, such that there is the opportunity for change. This input function is described by the MLP as being a change within the landscape level of the sociotechnical system that opens up opportunities for niche innovations to develop and provide solutions that will enable the changes proposed by these changes within the landscape to occur in the incumbent regime. This Geels calls ‘windows of opportunity’ (Geels, 2002), which by definition suggests that the opportunities exist within a short timeframe. The global sustainability challenges do not occur over a short timeframe, in fact many have been problems that humanity has been struggling with for decades. Furthermore, this is The Conundrum that has developed out of Geels’ own work, where he recognises that the changes provided by the landscape are still not enough to allow the niche innovations to cause a transition of the regime.

Since many niche technologies take five to 10 years to develop and market, perhaps one could say that for technological transitioning a window of opportunity while opened due to a disruptive change in the landscape, stays open over a very long period of time. This means that changes in the landscape create a possibility where change can occur. The window of opportunity once initiated, offers opportunities for niche technologies to develop, until a new change within the landscape occurs, which in the UK energy field has been more than 20 years.

## **3.6. Summary and Conclusions**

The main aim of this chapter was to identify a theoretical framework that could contextualise and help in the understanding of the transition goal of this research. From several theoretical

frameworks the multi-level perspective on sociotechnical transitions was chosen. From all the literature several gaps were identified within the sociotechnical transition theory for further research. Further analysis of the MLP revealed weaknesses in the identification of the institutions and institutional structuration within the regime level of the theory. It suggested that the electrical regime was a two-dimensional plane whereas this research sees it as a three-dimensional cylinder, where actions/decisions are taken within an institutional structure that is part of a five level structure within the sociotechnical electricity regime. It has shown that power and politics can define and change the landscape pressures which led to the conclusion that the landscape is not exogenous and as slow moving as described by the conventional model.

The literature highlighted a misalignment between how energy policy has created opportunities both in the smart-grid and renewable energy generation arenas that have over the last twenty years not been able to actually make big impacts on the incumbent systems. This has been identified as ‘The Conundrum’ which has now become one of the gaps in the literature which this research seeks to understand.

The main aspect of the literature search and discussion within the last two chapters was to see if it would be possible to identify from the literature a transition pathway for DC voltage to proliferate within the UK, however this was not found. This therefore is still the basis of this research, to identify how DC voltage in the UK can become proliferate. To do this a research methodology will be formulated in the next chapter.

# Chapter 4

## Methodology

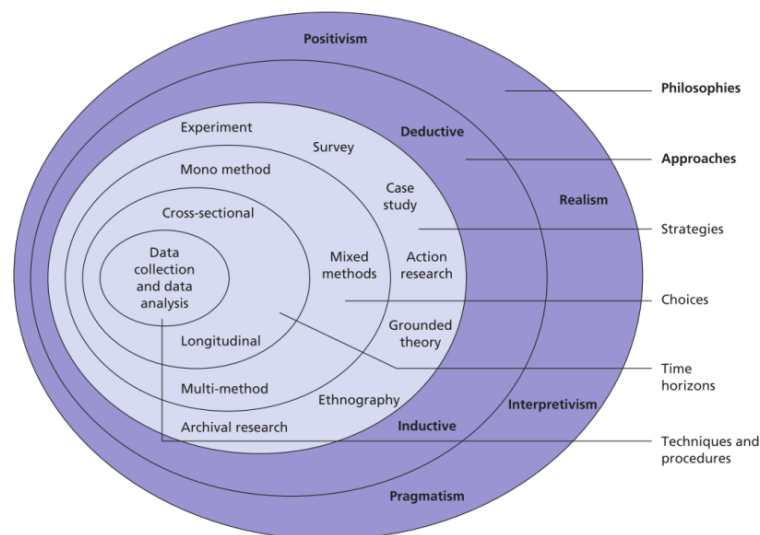
### 4.1. Overview

The aim of this research is to identify a transition pathway within an electricity system. The system chosen for transitioning is the centralised AC electrical system within the UK. The transition that is in focus is a change of the present centralised alternating current electrical system to one that is of a distributed direct current nature. A transition therefore implies a change from a system with certain characteristics to one that has different characteristics. The main aim of the data gathering for this research is to identify the **processes** that will have to happen for a successful transition to take place. The theoretical framework used is that of the Multi-Level Perspective of sociotechnical transitions (MLP), as described above in Section 3.2. Change has to be made across a wide spectrum of social networks (see Figures 3.5 and 3.6 for more details), which involve decisions made by many actors within many different institutions. The label ‘institutions’ identifies a very wide range of structured activities as defined by Hodgson (2006) (see Section 3.2.6), and institutional change occurs within the structuration of the institutional (Section 3.4.3). Before it is possible to understand how a transition can take place, the present institutional structuration and how a transition will affect all institutions in the current sociotechnical electrical regime, will have to be understood. From the gathered data a transition timeline will be developed.

This chapter will lay out the research methodology and data gathering processes used by this research to gather data about the whole sociotechnical electrical system. The methodological process follows that of the research onion (Saunders et al., 2009) which is as follows: firstly to understand where this research fits into the different available research philosophies, then to identify what data gathering strategies are available, to understand which methods are available to analyse the data, and finally to identify a method to represent the data (see Figure 4.1 below). The result of this process will be to choose a method(s) to gather the data, which analytical approach will be used to identify/extract finding from the data, and how to present the data in an easy and meaningful way.

## 4.2. General philosophical framework - The research onion

There are many schools of thought among different academic disciplines as to which approach to take when carrying out research. However, all agree that a defined and prescribed pathway for the research is necessary for success. Therefore, research must be carried out within an explicit philosophical framework and should adopt and justify an appropriate methodological approach. The diverse philosophical and methodological approaches are brought together in what has been coined the “research onion” (Saunders et al., 2009, p. 128).



**Figure 4.1**  
The research 'onion'  
Source: © Mark Saunders, Philip Lewis and Adrian Thornhill 2008

Figure 4.1 The different research philosophies and approaches - the research onion.

Figure 4.1 has three sections, the outer two rings are the mind-frame of the researcher, the middle three rings are the methodological frameworks that provide the focus for the research and the core is the method/s used to gather and analyse the data. The method used for research will depend on the approach of the person doing the work and the subject under examination. The person will come to the research with prior knowledge, skills set, experience, a personal nature, and hopefully an enquiring mind. Framing the research in a mechanism that sets out a descriptive pathway for the work, should ensure the rigour of the research and the validity of its conclusions.

#### 4.2.1. The research philosophy and approaches in more detail

The research onion provides a huge spectrum of possible pathways a researcher can use. The methodological approach chosen will be very much dependent on the nature of the problem under consideration and the researcher, therefore some of the pathways will be mutually exclusive. This research has both social and technical aspects to it. The technical aspects are less open to interpretation and have a more fixed reality, while the social aspects are more open to individual interpretation and “mind set”. Therefore, while for some research projects there may only exist one set of methodological pathways’ which exclude other approaches, for this project, due to its sociotechnical nature, different approaches may be employed for different aspects. Before considering the methodological framework for this research it is important to understand a generalised philosophy of research methodologies.

**Ontology** is the philosophy that studies *the nature of reality* or being, and the **epistemology** is the branch of philosophy that studies the *nature of knowledge* and what constitutes acceptable knowledge in a field of study. (Saunders et al., 2009)

According to the **positivist** ontology there is a single, *external and objective reality* to any research question regardless of the researcher’s belief. The positivist researchers attempt to remain detached from the participants of the research by creating distance between themselves and the participants, is what Saunders calls “*a value-free way*”. This is an important step in remaining emotionally neutral to make clear distinctions between reason and feelings as well as between science and personal experience. Positivists also claim it is important to clearly distinguish between ‘*resources*’ research that rely on facts and ‘*feelings*’ research which rely on value judgement.

The technical aspect of the electrical system is a physical/technical system and is therefore an aspect that is independent of people, which implies that the technical aspect of this research has a positivist aspect to it. However as the technical system is not “*an observable social reality*” that leads to “*law-like generalisations*”, it is not positivistic within the definition as described in social science text books (Robson and McCartan, 2015; Saunders et al., 2009; Wisker, 2008)

**Interpretivists** on the other hand, believe that the reality is relative and multiple. According to this tradition there can be more than one reality and more than a single structured way of accessing such realities, they are very difficult to interpret as they depend on other systems for meanings. An interpretivist researcher enters the field with some sort of prior insight about the research topic, but assumes that this is insufficient in developing a fixed research design due to complex, multiple and unpredictable nature of what is perceived as reality. The researcher remains open to new ideas throughout the study and lets it develop with the help of his informants. Crucial to the interpretivist philosophy is that the researcher has to adopt an empathetic stance. The challenge here is to enter the social world of our research subjects and understand their world from their point of view. (Saunders et al., 2009)

The social aspects of this research are strongly **interpretive**, as it attempts to understand how people within institutions create structures, and make changes to the mechanisms that govern the electrical system. Due to the relationship between people and the electrical system, different people may have their own perspective of what the mechanisms and structures that govern the operation of the whole sociotechnical electrical system are, this therefore adds an epistemological dimension to this research.

The following explanation on the term **realism** is given by Flowers (2009, pp. 2-3 );

*“In common with interpretivist positions, realism recognises that natural and social sciences are different, and that social reality is pre-interpreted, however realists, in line with the positivist position also hold that science must be empirically-based, rational and objective and so it argues that social objects may be studied ‘scientifically’ as social objects, not simply through language and discourse.”... “Realists take the view that researching from different angles and at multiple levels will all contribute to understanding since reality can exist on multiple levels (Chia, 2002) and hence realism may be seen as inductive or theory building.”*

This research, being interdisciplinary, has a strong realist approach as it looks at the technical effects of a distributed electrical system from multiple angles including how the whole fabric of society is affected by electricity or the lack thereof. Therefore, this research is mainly interpretivist knowledge (epistemology) but is also realist as it is also dealing with a real world (Ontology) electrical system. This research is about a specific future transition in the energy field. It is therefore goal orientated or ‘preparative’ (Smith et al., 2005), whereas many



of the historical transitions, discussed in the transition literature, were ‘emergent’, i.e. they developed out of entrepreneurs exploring commercial opportunities related to new technology.

This research takes the bottom up approach, and uses inductive reasoning to develop the understanding of the research problem and ‘qualitative research’ methods to gather data. Quantitative based research which involves mass data gathering via surveys or mailshots etc. will not be carried.

#### **4.2.2. The position of this researcher**

With a background in Electrical and Electronic Engineering, the practicalities of transitioning are foremost in the mind. In Electronic Engineering, it is about designing for worst case conditions and therefore building in robustness and sometimes redundancy. This approach developed this researcher to be analytical and perhaps critical. Therefore, this researcher could be described as a critical analyst who is a realist as well as a theorist. Doing research in a sociotechnical field makes this researcher a boundary spanner (Williams, 2010) bridging the gaps between the disciplines of engineering, social science and political science.

From the theory, it is important to identify institutional structuration of the many institutions within the social networks (Figure 3.6), of the electricity system. This includes enablers and barriers, who are the decision makers and how long does change take to ‘percolate’ through an institution. Therefore, the social science literature was looked at to identify data gathering methods. Within the literature there are many strategies for data gathering. Some of them were investigated before one was chosen for this research.

### 4.3. Strategies and Choices for data gathering

The next stage in developing a research method is to decide which strategy to use and how it will be realised.

#### 4.3.1. Ethnography

The ethnographic approach is an embedded one, where the researcher lives or spends time amongst the people being studied, observing and talking to them. This is done to gather data in order to produce a record of their beliefs, behaviours, interactions, and events that shape their lives (Cunliffe, 2010, p. 230). The output from this type of research is a written account. How this account is presented depends on the approach of the researcher which Cunliffe presents as three distinct ethnographic research categories; *realist* ethnographers, *impressionist* (interpretive) ethnographers, and *critical* ethnographers. The difference between these approaches depends on how much of the researchers own beliefs and stance as to the meaning and interpretation of the data gathered, is included in the written record.

While there are many versions of *realist* ethnographers, in general they are concerned with removing themselves as best they can from the narrative and are focused with “telling it like it is”. They believe in being objective and dispassionate, factual reporting without personal bias and identifying true meaning (Saunders et al., 2009, p. 182) . “*They validate their work as being truthful to the research site by using qualitative and quantitative data, coding techniques, offering detailed accounts of the context and interactions, and/or identifying patterns and processes.*” (Cunliffe, 2010, p. 230). This methodology has the advantage of reporting ‘as is’, yet as the observer is an outsider, has the disadvantage of missing nuances that would only come out with a closer relationship with the subjects under observation.

*Impressionist* (interpretive) ethnographers on the other hand see the people they are observing as participants rather than subjects and see themselves as part of the process of interpreting and making sense of the data gathered. They believe in the possibility of more than one interpretation or meaning to what they are observing rather than a single true meaning. *Critical* ethnographers are concerned with critically analysing the underlying basis for different ethnographic research/texts. They look for possible political, cultural and any

possible outside influences that get in the way of our ability to create impartial, accurate and authoritative knowledge about the world. They embrace “*an ethical responsibility to address processes of unfairness or injustice within a particular lived domain*”(Soyini Madison, 2005).

For this research, an ethnographical approach has the advantages of being able to observe how people make decisions within the institutions in the social networks of the electrical regime, to find out first-hand about the ‘as is’ systems and institutional structuration. There also exists a large element of documentary evidence within institutions that would help in the understanding of their institutional structuration. Similarly, ethnography would also help to understand how a change to DC voltage may or may not affect the institution. However, the whole sociotechnical electrical system has many social networks each with multiple institutions, which makes it a very complex system. Therefore, the main disadvantage of using ethnography will be the length of time it would take to carry out multiple ethnographic studies. Furthermore within the definition of an institution as described by Hodgson (2006) in Section 3.2.6 above, and when one looks at Geels sociotechnical configuration (Figure 4.6 below), some of the institutions are conceptual with no single group or place for an ethnographic study, these include, markets, regulations, and finance. Therefore, an ethnographical approach for this research is not feasible.

#### **4.3.2. Archival research**

Archival research is the use of administrative records and documents as the principle source of data (Saunders et al., 2009). Archives by definition hold historical data, which is gathered over many years and is not there to answer any specific research question, but rather to preserve the ongoing activities of an institution, this therefore allows the researcher to study the historic daily reality of the institution. The researcher trawls through the archive to find data to answer a specific question. This research needs to understand present day institutional structuration, i.e. it is about what is happening now within the structures of the institution and in the mind-set of institutional actors. Furthermore, as this research is about a future transition, the future direction of the institution is very important. Therefore, archival

research is not a possible principle method to ascertain present institutional structuration and the future direction of an institution.

Besides archives, many institutions produce information in text form, be it in a printed form or in digital form, this type of data is called secondary data (Saunders et al., 2009, Section 8.2 ) which will be very useful for this research. However as Yin (2014, p. 106) points out, this data may be inaccessible due to privacy constraints. He also points out (on page 108) that there can be bias within documents that may have been written for a specific purpose and audience other than that connected to the researchers' project. While this methodology has been rejected for the prime data gathering it is not ruled out for gathering secondary data that will inform the methodology approach that shapes this research.

#### **4.3.3. Survey and Questionnaires**

A survey is a deductive approach strategy, and often sets out to answer 'what', 'who', 'where', 'how much', and 'how many', type questions (Saunders et al., 2009, pp. 176-178). One of the main methods of carrying out a survey is using questionnaires, which is a highly economic way of collecting data from a large population. Standardised questions allow for comparisons to be easily made. While data analysis can be time consuming, the data can also be used to suggest correlations and relationships between variables and can be used to produce computerised models. Findings from the data can then be extrapolated to produce representative conclusions for a larger population. Problems with this method of data collection include; not having a representative sample, having too small a sample, people won't necessarily report their beliefs, attitudes etc., all the information required must be known in advance and there is no ability to clarify an answer, and it is possible to make a bad or an unfocussed survey (Robson and McCartan, 2015, p. 285).

A survey can also be carried out using standardised questions within a structured interview or observation. This method is not very appropriate for this research due to the fact that a full set of the same questions cannot be asked to different actors in different social networks and institutions. While many of the core questions may be generic to all institutions, each institution will have a different internal structure and have different mechanisms for change to

occur. Also institutional actors have different backgrounds and knowledge bases that make them best able to provide specialist information. Therefore, this method was not used.

#### **4.3.4. Grounded theory**

Some research, which in many cases is scientifically based, begins with a theory that the researcher would like to validate or develop. In such research the theory drives; one, where to focus to derive data, and two, who is best fitting to provide the data, i.e. the data follows the theory. With grounded theory the researcher study's a real world phenomenon by gathering data via personal or someone else's experience from which a theory is developed (Wisker, 2008, p. 213), i.e. "*the theory is grounded in the data obtained during the study*" (Robson and McCartan, 2015, p. 146). Or as Robson & McCartan (2015) put it " *...the systematic discovery of theory from data, so that the theory remains grounded in observations of the social world, rather than being generated in the abstract.*". Usually the data is qualitative however, it can also be quantitative (Robson and McCartan, 2015). This methodology accepts that there can be multiple perspectives to any given reality. The data will steer the analysis, rather than confining the analysis to reconceived concepts or themes. This means that concepts and themes emerge from the data.

Traditional research, where there is one stage of data gathering followed by data analysis is said to be 'linear'. However, with grounded theory, there are multiple rounds of data gathering, each followed by data analysis. Each analysis feeds into the next round of data gathering, until the data gathering stops when new data does not add to what is already known. The data gathered is usually qualitative, but it can also be quantitative. (Robson and McCartan, 2015, p. 148). When interviews are used, the data is in the form of transcriptions. By reading transcripts, categories are assigned to emerging concepts. These concepts are then grouped into different themes. Then to test how each interviewee either fits into each theme or not, and to record not only what findings may emerge from an interviewee but also what the interviewee did not mention or may not know the answers to an important theme, a cross interviewee analysis is carried out. The goal is, that a theory that sheds clarity and a new light on the research topic, should emerge

The output of this research is to develop a transition framework for the electrical system based on the MLP model on sociotechnical transitions, as its theoretical model. It does not seek to develop new theories. Therefore, grounded theory is inappropriate as the basis for the methodology of this research.

Therefore, when designing a data collection process for a research project, there are many methodologies to choose from. Some of these have been briefly discussed here. This research is looking at a real world problem, how a technical system can transition. However, since the system under research is sociotechnical and interdisciplinary, data about how people interact with the technical system, will also need to be gathered. Therefore, what data gathering methodology is best suited for this research?

#### **4.3.5. Case study**

Yin (2014) defines case study as, a study that investigates a contemporary phenomenon in depth and in its real-world context. The case itself is the main subject of the study and is usually a concrete entity. Some examples he gives for a case are: a person, organisation, community, program, process, practice, institution or an occurrence such as a decision. There are different forms of case study and it will depend on the researcher, and the research question which one is used. The case study strategy also has considerable ability to generate answers to ‘why?’, ‘what?’ and ‘how?’ questions. For this reason, the case study strategy is most often used in explanatory and exploratory research (Yin, 2014, pp. 171-172). This method may use quantitative as well as qualitative methods and in many cases uses both in the same study, which is called a ‘*mixed method case study*’ (Yin, 2014, pp. 65-66).

The data collection methods for a mixed method case study may include; interviews, observation, documentary analysis and questionnaires. If the data has multiple sources, then ‘*data triangulation*’ can be used to find if there is any convergence to points that validate a conclusion from different sources. This makes the conclusions more robust, (Patton, 2002). The case in the study can be one, as in the ‘*single case study*’, or more as in the ‘*multiple-case study*’. The multiple-case study allows for validation and replication over several different cases. Case study has been identified as the most appropriate method for this research. The

‘*multi-method*’ is one where the researcher combines “*more than one data collection technique*” (Saunders et al., 2009, p. 152)

#### **4.4. Choosing a research method**

A transition by definition has an ‘as is’ state and a ‘new’ state. Therefore data will be needed to shed light of these states, i.e. how the institutions operate, and the mechanisms that will enable or block change, this part of the data gathering is called an *explanatory case study* (Yin, 2014, p. 238). The use of DC electricity will cause a change in the present UK electricity system and produce a final system that defines a ‘new’ state. Therefore, the data gathered should be able to shed light on what the new system will look like, the interactions between the different institutions and social networks, and the configuration and possibility of implementing a DC system, this part of the research is therefore described as an *exploratory case study*. Therefore, from all the possible methodologies described by Saunders, the ***multi-method single case study*** is the one that best matches this research. It will have one case the sociotechnical electrical system in the UK, and it will use multiple techniques and sources for data collection. One of the techniques that will be used is interviews (Saunders et al., 2009, Chapter 10).

There is a paradox with regard to the usage of (single) case study as a research tool, on one hand it has been used in the past to produced seminal research in many disciplines, (especially political science) and yet it is held in low esteem or ignored by academics, (within political science) as a research methodology (Gerring, 2004). There has been criticism that case studies especially single case studies cannot be used to make generalisations and that they can be biased towards verification of the researched preconceived notions. Denzin and Lincoln (2011, p. 302) identify five criticisms of the use of case study, which they then term ‘misunderstandings, and not criticisms. Denzin and Lincoln list (p. 304) many instances of the successful use of single case studies, which were critical to the development of the field of science. This research is focused to develop a transition pathway for the UKs’ electricity. While the generalities of the physical systems of all centralised electricity systems are very similar the complexity are different in each country. Therefore, it is left to further research to

discover the transportability of the transition model that will be developed for the UK for other countries.

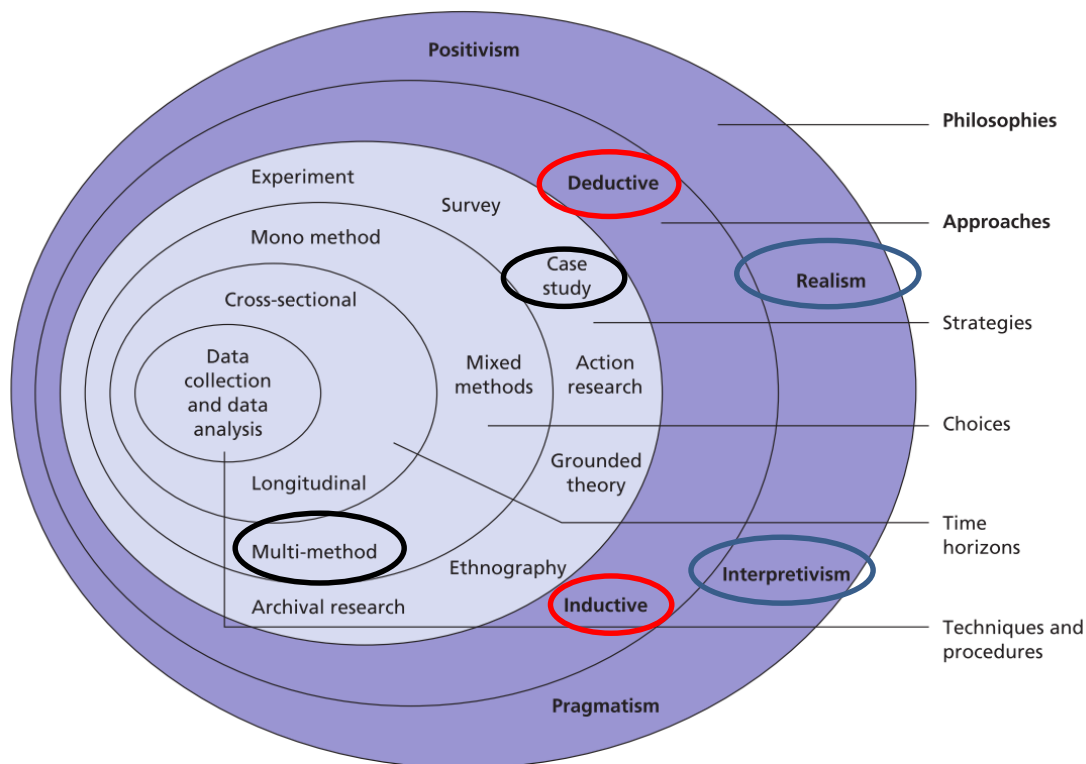
The following methodological terminology and understanding has been formulated using Wisker (2008). Much of the information about institutional structuration is either documented, or ingrained in the way 'things are done', therefore one may think that a positivist methodology needs to be used to gather the data. However, the structure of the decision-making process, while it looks like an '*observable reality*', it relies on the ability of people to make decisions within the framework of the institutions ethos. Therefore, there is scope for people's opinions, beliefs, and values to be incorporated in the decision making process. This therefore implies that the nature of the data collection will also be interpretive. As there will be few opportunities to interview more than one key person in any individual institution the data gathered will be qualitative rather than quantitative, which has the disadvantage that it is harder to identify which part of the data from any one individual is interpretative or positivistic, i.e. which is their own opinion and which is institutional structuration. The best method of gathering this type of data is therefore via an interview rather than via a questionnaire. Interviews will not only provide raw data on the institutions but will also provide interesting contextualisation of decision-making processes not easily extracted via a questionnaire. The interviews will be targeted at key people who are able to best describe how DC may affect the structuration of their institution.

From the theory it has been shown in Chapter 3 above, that sociotechnical systems have a complicated configuration (Figure 3.3), have both fixed, (the technical) and interpretive (social) realities and exist within the type of research that spans different disciplines. Also the data required from each institution has elements that are generic to other institutions and elements that are unique to a particular institution. Therefore prior to gathering any data it will be difficult to formulate some of the questions about unknown unique elements of an institution. Therefore the interviews will have to be semi-structured (Robson and McCartan, 2015, p. 285).

Figure 4.2 below shows ringed the overall framework of the research methodology for this research. The interviews will be transcribed and together with secondary texts, the data will



be categorised and harmonised to produce a transition framework that will mirror the theoretical framework as set out in Section 3.2 above.



**Figure 4.1**  
The research 'onion'  
Source: © Mark Saunders, Philip Lewis and Adrian Thornhill 2008

Figure 4.2 The words encircled are methodological descriptors that frame this research.

#### 4.5. The theoretical framework for this research

Markard et.al (2012), explain in length four emergent fields of transition studies. In simple terms they explain that Transition Management is about “...*influencing ongoing transitions into more sustainable directions*”, Strategic Niche Management, as its name implies focuses on the niche and how niche innovations interact with the regime, and Technological Innovation Systems is the study of “...*emergence of novel technologies and the institutional and organizational changes that have to go hand in hand with technology development.*”(see

Figure 4.3). The Multi-Level Perspective (MLP) looks at technical transitions, on three levels of *niche*, *regime* and the *landscape* and includes institutional studies.

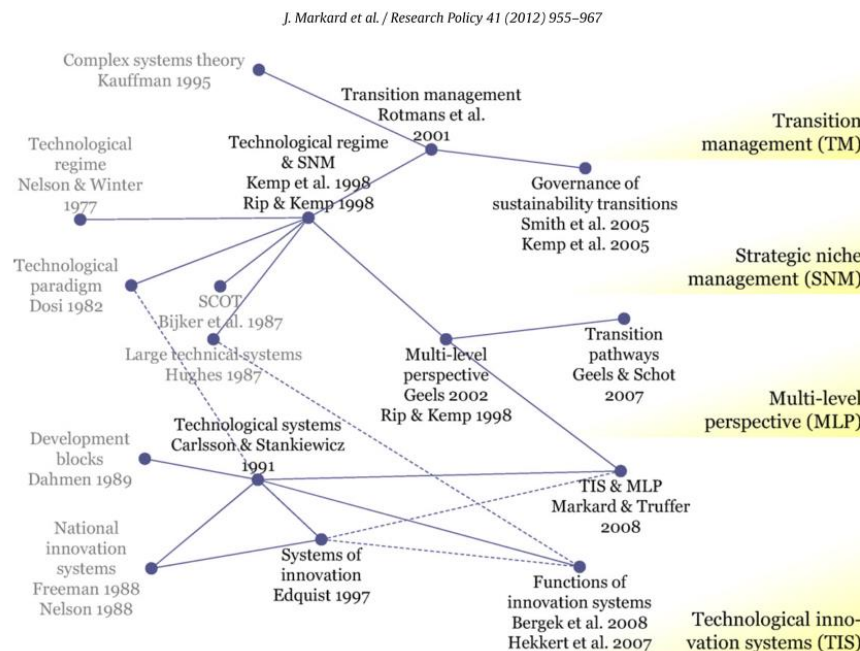


Fig. 1. Map of key contributions and core research strands in the field of sustainability transition studies.

Figure 4.3 Four conceptual frameworks central to sociotechnical sustainable transition studies.

This research considers a bottom-up approach, which starts at the consumption side of the electricity system within the built environment and then considers the generation/supply side. It looks at a *niche* innovation of using DC voltage systems within the built environment. In order for this innovation to succeed it will have to be able to proliferate within the existing electricity *regime*. To do this it has to cause a transition of the whole sociotechnical electricity system, which includes effects on all *landscape* pressures and the *institutional* structures connected to the incumbent AC system. The only one of these four transitions studies that encompasses all the aspects of the whole transition is the MLP. Therefore, this theoretical framework was chosen for this research (see Section 3.1).

The sociotechnical nature of the electrical system implies that to understand the transition process, will not only require data from an engineering perspective, but also sociological and political data from social science and political science perspectives. This makes this research cross-disciplinary by nature.

The theoretical framework chosen was the multi-level perspective (MLP) on technical transitions of Geels (2002). A generalised transition pathway from an AC electrical system to one where DC will proliferate is shown in Figure 4.4 below. Transitioning takes place within the ellipse at the centre of the diagram.

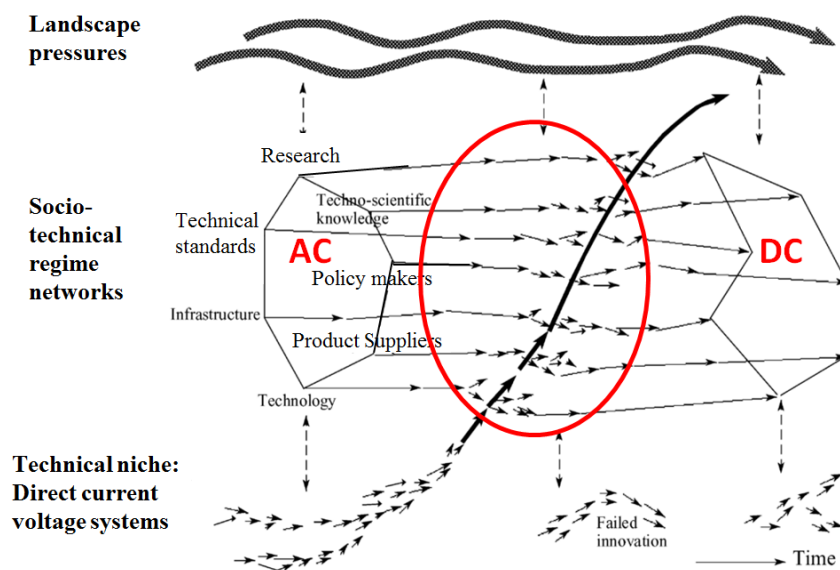


Figure 4.4 A generalised transition pathway within the MLP of a sociotechnical transition (adapted from Geels, 2002, Fig. 5).

A transition by definition implies an initial state and a final state, the mechanisms and pathway between the states is the transition process. Therefore, before the mechanism of transition from an AC electrical system to one where DC can proliferate can be understood, it is important to understand all the characteristics of the ‘as is’ AC electrical system. In Section 3.2.5 four possible mechanisms for a transition are articulated, the result of each is a new regime. The MLP explains that the regime is made up of social networks within which are institutions that will go through the transition process, this is depicted as the multiple arrow pathways within the ellipse in Figure 4.4 which post-transition becomes the new pathway. In Section 3.4.3 above it explains, that the process of change within an institution, which includes norms, rules and actors (Section 3.1), is described as the structuration of the institution.

The rules, regulations, laws, and policy etc. that govern the electrical sociotechnical system have evolved over the last 130 years. The institutions that create, help evolve, implement and govern all aspects of the electrical system have their set ways of functioning. To make changes within the institutional structure there are set pathways. Transitioning to new electrical systems, will require institutional actors to adjust their structuration to start thinking in terms of distributed DC electricity systems, as well as a new set of rules, regulations, laws, and policy etc. that surround the technical system. Therefore, it is important not only to understand the structuration of the current *modus operandi* of an institution, but it is important to know the channels for introducing new ideas into the institution that may require the incumbent structuration to change, i.e. the transition to DC will change the structuration and outputs of many aspects of the institutions within the sociotechnical AC electrical regime. It is therefore crucial to identify the mechanisms and pathways for change, in the institutions themselves.

In many institutions, institutional change may meet resistance, hence the need to identify enablers and barriers to change. Therefore, the data that this research will gather to help identify transition pathways will include: structural mechanisms within the institution for changes to occur (institutional rules, etc.), who the facilitators are, ramifications of a change on and by outside institutions, enablers and barriers, and how DC voltage systems fit into the structuration of the institutions. Some of the institutional data has been identified in chapter 2 and include: components of the technical systems, finance, standards, energy policy etc. which can sometimes be the enablers, barriers, or institutional inputs and outputs themselves.

No institution, especially one in a sociotechnical system like the electricity system, operates in isolation. There will be external pressures on the institution, and its outputs/decisions may affect other institutions. This two-way influence may also exist on and from the decision makers themselves. These external connections act as interconnections and pathways, i.e. they are boundary spanners (Williams, 2010), for dialogue between different institutions and different social networks. It is therefore important to gather data about these dialogues and interconnections, i.e. to identify ‘boundary objects’ that according to Akkerman & Bakker (2011) who quotes (Star, 1989) “*refers to artefacts doing the crossing by fulfilling a bridging function*” between different institutions. Figure 4.5 shows a diagrammatical representation

of the interplay between the main variables that are; actors, institutional structuration, enablers, barriers, decisions, and external connections.

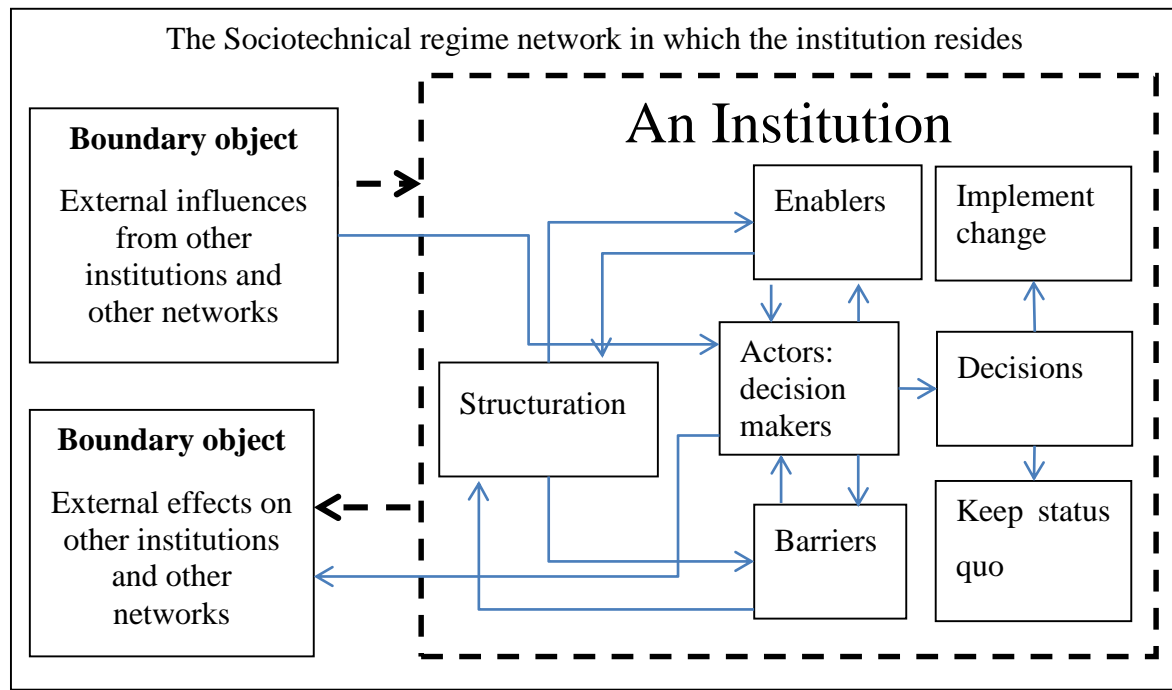


Figure 4.5 A diagrammatical representation of the interplay between actors, institutional structuration, decisions and boundary objects.

In his 2002 paper, Geels was trying to answer the following question: How do technical transitions come about? His case study was transportation. In his paper he mapped the elements of the sociotechnical configuration of personal transportation, Figure 4.6 below. This shows the complexity not only of the technical system but also the societal elements that are linked and aligned to each other to form the existing sociotechnical configuration of the transportation system.

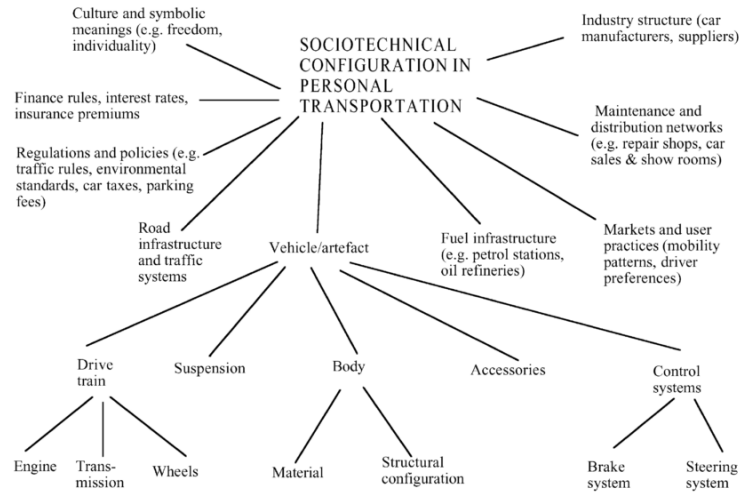


Figure 4.6 Elements from the sociotechnical configuration in transportation (Geels 2002 Fig 1).

The electrical system is no less complex than that of the transport system. This complexity will have to be taken into consideration when formulating the methods for data capture. This research is aimed at answering the following question; how can a mature AC electrical system transition to a system where DC voltage is proliferate?

From Figures 3.6, 4.5 and 4.6, many elements of the type of data points that will need to be collected are identified. These come from both the literature review and the literature connected to the theoretical framework of this research. The main data variables that are needed in order to build the case study to understand the as-is and the transition are split up into the following three areas of interested.

(1) **Description of the system at a higher level** - These first 4 points come out of the MLP theory of Geels (2002, 2005, 2007) which is explained in more detail in Sections 3.2 above.

1. There is a need to understand the as-is present sociotechnical system
2. Need to identify the social networks in the electrical regime
3. Need to identify the institutions that are in the social networks
4. Identify which components of the present AC system will have to change or adapt to the usage of DC voltage electricity

(2) **Description of the system at a deep structural level** - these points come out of the institutional structuration theory as explained in sections 3.2 and 3.3 above.

5. Need to understand institutional structuration
6. Need to understand the mechanisms used by actors to make decisions
7. The enablers and barriers that affect what decision is made

(3) **Description of the transition** – these arise from both the literature about the MLP theory and the institutional structuration literature

8. Understand how the transition to DC will affect the components of the sociotechnical electrical system
9. Understand how the institutions will be affected by a transition to DC electricity
10. Different mechanisms for successfully developing innovations within the niche
11. Ways for DC to encroach and prosper within the regime
12. What underlying and external help will be needed for DC to proliferate

With these points in mind, a data collection framework to gather the data will now be explored.

#### **4.6. The multi-method case study**

In the previous section, the multi-method single case study was identified as the method that will be used for the data gathering part of this research. Two sources of data have been identified: published data in all its forms and oral data from institutional actors. When conducting a case study it is important to set out a protocol to insure success. This case study protocol, is based on the outline given in Figure 3.2 of Yin (2014, p. 84), and comprises, an overview, the data collection procedures, the questions that need answering and the analysis of the collected data.

##### **4.6.1. Overview of the multi-method case study**

The case study was developed by gathering data via a literature review. Then the sociotechnical AC system was characterised to determine what the social networks within the sociotechnical regime of the electrical system were. As many institutions as possible that made up each social network were then identified. This case study then analysed the

institutional structuration of the institutions in the present AC social networks to understand how change occurs within the institutions, what effects their outputs have on outside institutions, and what effects outside influences have on their outputs (Figure 4.5 above).

The aim of this research is to produce a transition pathway for DC voltage proliferation that incorporates all the individual pathways of change, within and between all the institutions. This transition will happen only when a whole set of changes align across many institutions within many social networks. The **data required** will be about; ‘*actors*’, who are the people who operate within institutional structures, the ‘*rules*’ which govern the actual technological system as well as the institutions with the social networks of the electrical regime, and the ‘*artefacts*’ which are the different components and outputs across all the institutions of the whole sociotechnical electrical regime.

#### **4.6.2. Data from published literature**

This research has encountered the use of four terms to classify data or literature, these are; “*primary data*”, “*secondary data*” and “*tertiary sources*”, and “*grey literature*” (Robson and McCartan, 2015; Saunders et al., 2009; Wisker, 2008; Yin, 2014). These terms have specific meanings within different disciplines and within the context of the type of research undertaken. Furthermore, the level of the output of the research using the gathered data can also determine whether it is given a “*primary data*” or a “*grey literature*” classification. For example, according to Saunders (2009, p. 69) government documents, and unpublished manuscripts are primary data, while books and journals can be classified as secondary literature sources, whereas in the academic world non-peer reviewed government documents would be looked at as grey literature while peer reviewed journals are looked at as primary literature. Therefore, as the labels given to data could be context and subject sensitive.

In this research there is a distinction between data gathered from literature that forms the literature review of the ‘as is’ system, and data that is used to inform the methodology approach that shapes this research. The first identifies gaps in the knowledge and provides context for the usage of distributed DC electricity systems, the latter is used to operationalise the MLP to identify the networks within the regime and shapes much of the framework for



primary data collection via the interviews. Therefore, within this research the data is defined as follows:

1. Primary data, is the data from interview transcripts
2. Secondary data, all other data used to inform the methodology approach that shapes this research

A purposive sampling strategy (Saunders et al., 2009, pp. 234-240) was used to identify relevant documents that discuss the strategies, structures and behaviours of the UK's energy system. This includes anything that is relevant to the actors, operation, policies and strategies that inform the frameworks within this research. Examples of these types of documents include;

- Policy documents – for example relevant EU documents, (European Union, 2003) and DECC market reform plan (Department of Energy and Climate Change, 2013)
- Strategy documents – for example DECC energy efficiency and energy security strategies (2012a, 2012b) and Ofgem's (2010) demand side response document.
- Standards documents – for example IET Code of Practice for DC (IET Standards, 2015)
- Applicable regulations – for example the IET's (2015) wiring regulation

These documents identify the current or potential future states of the socio-technical regime and directly support the primary interview data. Many of these are not subject to peer review as they are produced by government agencies or related institutions, such as standards bodies or well established communities of practice and professional membership bodies as identified by their role within the regime. Secondary data from individual companies were not included.

#### **4.6.3. Data collection using semi-structured interviews**

##### **(1) Introduction**

Institutional structuration, which defines many of the barriers and enablers for this transition, is in the hands of the institutional actors that yield the power within the institution. Therefore, to understand: who the actors are, under what institutional structures they operate, who holds the power for change, and what are the mechanisms to implement change, where possible,

institutional actors will have to be interviewed. The interview process and the general structure of the interview questions set out below came from the literature review.

## (2) General structure of the interview questions

From the literature review key issues for data capture emerged that became the heading of the interview questions as set out in Section 4.6.4 below. These are as follows:

1. What are the mechanisms for change within the institution?
2. Who are the people who influence change, from within and from without the institution?
3. What the interviewee knows about the AC system and DC Voltage?
4. What are the enablers and barriers that the interviewees can identify for the transition to DC voltage and for their institution to take up DC?
5. Horizon scanning: what can the interviewee tell about future trends of DC and their institution?

## (3) The use of semi-structured interviews

The sociotechnical regime for the electrical system comprises different social networks (see Figure 3.6). Different institutions and organisations that are associated with similar actions or outputs together comprise an individual social network within the sociotechnical regime. However, each is unique in its operational methodologies, ethos, goals, and its outputs. So while the core objectives of these institutions may be similar, in their operation many of them are completely different. This poses a problem when trying to understand how change occurs within a social network that is comprised of similar yet unique institutions. So although in general, changes in similar institutions in the same social network may occur in parallel, the methodology of change will be unique for each institution.

This is a problem when trying to formulate a fixed set of interview questions that would apply across all the different institutions in a single social network, how much more so for institutions in different social networks. Questions for one social network would not be pertinent for a different network. This meant that for each different social network the details of the questions would have to be different. The interviewer will need to have considerable

freedom in the sequencing of questions, in the exact wording to use, in being able to miss out or add questions during the interview and in the amount of time and attention given to both specialist and generic fields of knowledge. Therefore for this research semi-structured interviews are appropriate (Robson and McCartan, 2015, p. 285; Saunders et al., 2009, Section 10.2 & 10.3).

A semi structured interview is built around a list of core topics, some key questions and a set of prompts, (which could be targeted questions only appropriate to that interviewee and their position within their institution), that are used to draw out from each individual interviewee specialist information. This is what Barriball and While (1994) call “*probing*”, which allows for clarification, discussion and further exploration of initial answers given by an interviewee. The advantage of this method is that it is very suitable for a small-scale case study (Drever, 1995) like this research. However, there are problems with this type of interview process.

#### (4) Problems arising with the use of semi-structured interviews

The pitfalls and problems that an interviewee encounters are more manifest in a semi-structured interview than in a structured interview. Diefenbach (2009) highlights the following possible downsides with interviews, “...*subjectivity, the generalisation of the findings, conscious and unconscious biases, influences of dominant ideologies and mainstream thinking*”: Barriball and While (1994) identify the willingness or ability of interviewees to provide accurate information. This is especially pertinent to commercially sensitive information. With a semi-structured interview there is greater possibility that an interviewee could take control of the discussion in a tangential direction, or even try and become dominant within the interview by asking the questions and taking over the direction of the interview. Also it is possible that the interviewee when probed could become difficult, if they are ‘cornered’ by the questions. The goal of the interviewer is to remain calm and focused and not to become fazed at any time within the interview.

#### (5) How were the interviewees identified and procured?

To start with, it is important to know where power resides within the institution, so that the appropriate ‘decision makers’ are the ones targeted for interview. Knowing their decision-making processes or protocols, helps to understand what ability they have to create or unlock

barriers and enablers. The case study was also interested to know what level of knowledge about DC systems existed within the institution and whether DC electrical systems are on or could be put on the institution's agenda.

The MLP theory identifies the type of networks that make up the multi-actor networks of the sociotechnical regime (Figure 3.3). For the transition within the UK from AC to DC the social networks were identified and can be found in Figure 3.6. The interviewees were targeted so that at least one reputable representative could be interviewed from as many of these social networks as possible. It was important that they would be able to explain how processes of change occur within their institutions and how a transition to distributed DC electricity would impact or be impacted by their organisation, i.e. the institutional structuration. The people that were targeted for interview were engineers that work with, electricity systems, standards, manufacturing, and research. As well as non-engineers that work in the sustainability field that includes, think tanks, consultancies or niche academic and governmental institutions.

For a transition to take place people have to make decisions within the context of their institutional structuration, see Figure 4.5 above. It is therefore important to identify either the person in the institution who can affect change or an actor who fully understands the inner workings of the institution and can relay in the interview the process of change within their institution. Therefore, people in senior roles were targeted for interview. There are two types interviewees to identify, either the decision makers themselves or someone who understands the structure of the institution. Potential interviewees were found through networking. The first contact with potential interviewees was made by going to workshops, seminars and conferences, and then getting them to agree to do an interview. Some contacts did not want to be interviewed, so they were asked for the contact details of the most appropriate person in their institution, and/or to pass on this researcher's details. For appliance manufacturers, the first contact was made by telephone to try to ascertain who would be available for interview. Follow up emails were sent explaining that the best person would be a product manager who could answer questions about 'product life cycle' and if available someone who was an engineer. One of the problems was the lack of responses from appliance manufacturers; this meant that they were under represented within the data.

Snowball sampling or what is called chain referral sampling (Biernacki and Waldorf, 1981), was used to identify further interviewees and data from literature sources, i.e. citations from one paper were used to identify further literature. However, in reality both the data gathering and the identification of the interviewees did not, as the term suggested snowball easily. In fact, for the interviewees the first were identified at a conference, and only some of those gave one or two new contacts. So that the snowball effect stopped at the second level rather than as the term suggests there were third, fourth or even fifth order referrals. Some new interviewees were gained by asking each interviewee at the end of the interview if they have any contacts that could be potential interviewees.

The interviews were carried out over the telephone and digitally recorded according to the university's code of ethics. When asking sensitivity questions to potential high calibre interviewees about their institution's or about government policy it was recognised that they may not be willing to give candid answers during a recorded interview. Therefore, it was decided during the university's ethics approval process that the interview recordings and transcripts would remain anonymous. However, an anonymised transcript was sent to each interviewee for their consideration.

#### **4.6.4. Formulating a set of generic interview questions**

Experts in the fields that are associated with the sociotechnical transition of this research, in theory, should know about both the social and the technical aspects of the energy system. However, as this research is cross-disciplinary the data required for the whole transition by its very nature, encapsulates knowledge from different and diverse disciplines. Therefore, each individual is not expected to be very knowledgeable about subjects outside the realm of their expertise. It is important to note that if an interviewee may not be able to answer a question that is outside their field of knowledge, this will not reduce the validity of the data they provide that is within their expertise. Therefore, each interviewee was chosen to provide data about their particular field of expertise, to help add one part of the larger dataset required for the whole transition. However, it was still important to identify how much the engineers know and how important to them the social aspects of the transition are, and similarly for the non-

engineers what they know about the technical aspects of the energy system. Their answers may identify who is, who is not and how interdisciplinary the interviewees actually are.

The transition theory identifies the need to understand institutional structuration as the main ingredient to develop possible transition pathways. As this research is about transitioning to DC voltage, it is important also to identify what level of knowledge the interviewee has about DC electricity and if the organisation is connected to the subject in any way. However knowledge of DC electricity is secondary to the knowledge about their institutions structuration. Most people who are non-technical will understand their own institutional structuration but may not necessarily understand technical matters. By making knowledge of DC electricity a main criteria for choosing an interviewee this may have limited the pool of potential interviewees, therefore, it was given secondary priority.

The main data needed from the interviewees was the following:

1. To identify the experience and role of the interviewee, and what the institution does
2. The current *modus operandi* of the institution, i.e. the as-is structuration
3. The internal and external channels for introducing new ideas into the institution
4. To identify the mechanisms and pathways for change in the institutions themselves
5. To identify enablers and barriers to change
6. To understand how a transition to direct current voltage electrical systems may affect the structuration and outputs of the institution
7. What are their thoughts as to the merits or disadvantages of introducing DC

Note: the word *organisation* used in the generic questions below, will change for each interview with the actual name of the institution inserted instead. Similarly, the word *outputs* will be changed according to the outputs for each different institution, it may read, regulations, energy policy, training regime etc. As the profile of the interviewees was known beforehand, some of these questions were not pertinent to many of the interviewees and were therefore not asked.

A sample set of questions is given below. Not all these questions were asked to any single interviewee, they were a pool of questions that formed the generic framework for the interviews. Some of the questions were obvious and already known before the interview, however, they were asked in order to include the answers into the data.

## SECTION 1: Background information about you and your organisation

### A: About you

- What is your background and experience?
- What is your position within the *organisation* and your main responsibilities?

### B: About your Organisation

- How would you describe the type of organisation you are working for?
- What does your organisation do and what are its goals?
- How does it go about fulfilling its goals?
- In which regions of the UK does your organisation operate (e.g. England, Scotland, Wales Northern Ireland)?
- Does your organisation support R&D in anyway with respect to energy reduction in the built environment?

## SECTION 2: Structures for Change

- What is the decision making process to implement something new or different?
- What drives change?
- When developing a new output or changing an existing output, which departments within your company have influence on its design / development?
- When developing a new output or changing an existing output, which external people / organisations have influence on its design / development?
- What protocols exist to facilitate change?
- What is your organisations' review cycle?
- What are the criteria that would initiate change of an output?
- What are the stages in the development or change of an output?
- How do you implement or action change, can you give an example?
- When an existing output is slated for minor change how long (on average) does it take to implement?
- Who are the main people who make decisions for change?
- What is the job title or from what departments are the main people who make decisions for change?
- When a complete redraft or a new output is needed how long (on average) does it take to implement?
- When is the next scheduled review of your output/s?
- Do you have documented procedures or reports that will help in the understanding of the change process?

## SECTION 3: Influence on change, from within and from without

- Is change to your outputs initiated from within your organisation or from without?
- What relationship exists and how does your organisation work with outside organisations?
- Does your organisation work directly with architects / developers / installers / homeowners to promote use of the domestic electricity technology?

#### SECTION 4: About DC Voltage

- Do you have any comments about the present centralised AC electrical system?
- What do you know about the use of DC voltage in the built environment?
- Which outputs of your organisation are directly connected to the use of electricity in the built environment?
- If DC electricity was to be implemented how would this affect the outputs of your organisation?
- What level of expertise is there within your organisation about DC voltage electricity?
- Does your organisation have any policies specifically relating to the use of Direct Current voltage in the built environment?
- Which output/s of your organisation are directly connected to the reduction of the use of electricity in the built environment?
- Do you have any thoughts as to how distributed DC voltage could proliferate?

#### SECTION 5: Enablers and Barriers

- Are there any time restrictions on changes to your present outputs?
- Which bodies / interest groups do you see as a positive influence on the adoption of DC technology?
- Which bodies / interest groups do you see as a negative influence on the adoption of DC electricity?
- Do you think that the government is doing enough to help reduce the energy used and the carbon footprint of the built environment?

#### SECTION 6: Any other questions & reflection on the interview and close

- How do you now intend to further develop the use of DC voltage within your organisation's outputs?
- In five years' time do you think that your outputs will have taken into consideration the use of DC voltage electricity?



- What do you think maybe different in five years' time - the technologies, regulations, and desires by end-users?
- Are there any comments or issues you would like to add or discuss from the interview or the research project?

Once an interview had been secured, the questions were then honed for that particular interviewee and their organisation, so that the questions each interviewee received had a similar general framework but were particular to the expertise of the interviewee and their organisation. It was realised that there will be aspects about the institution under discussion that would not be known to the interviewer therefore, it was envisioned that when such subject matter came up, a new line of inquiry would be pursued. While the structured questions were the foundation and framework for the interview, other questions were asked. The interviews were digitally recorded and a full transcript was written up. At all times the University's ethical framework was used. For an example anonymised interview transcript see Appendix 4

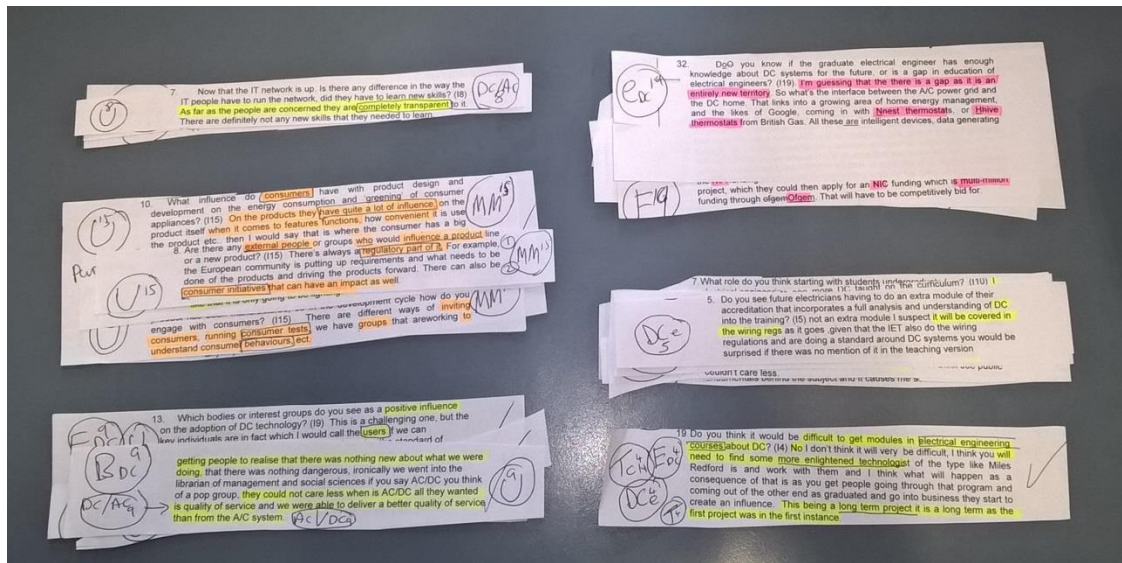
#### **4.6.5. Methodology for data analysis**

Saunders et. al (2009) have a whole chapter dedicated to the methodologies to analyse qualitative data, and similarly Braun and Clarke (2006) in the introduction to their paper identify many analytical frameworks and tools to analyse interview data. They mention three main inductive based methods that incorporate data analysis methodologies, *grounded theory*, *discourse analysis*, and *narrative analysis*. The interviews came out of the theoretical framework and the model of the institutional networks within the sociotechnical electricity system. As discussed above in Section 4.3.4, *grounded theory* is not appropriate for this research and neither are its data analysis methodologies. The details given by the interviewees that point to components of the transition process are what is important, and not the way the interviewees used language to convey their points. Therefore, *discourses analysis* and *narrative analysis* were not used to analyse the interview transcripts. As the interviews were semi-structured, each being tailored for a particular interviewee, there is no need to compare what each interviewee said about any given question, therefore *content analysis*, which is a method to compare the answers given by different interviewees, was not used. This leaves us

with ‘*thematic analysis*’ (Boyatzis, 1998; Fereday, 2008), which will be used to analyse the interview data. The methodology used to analyse the data was based on the six-stage thematic analysis process described by Braun and Clarke (2006), which is as follows:

The first phase is to familiarise oneself with the transcripts. This not only entails ‘repeated reading’ of the transcripts, but also at the same time searching for meanings and patterns. As these emerge and even before the next stage, one should take notes or mark ideas on the transcripts or make an initial list of ideas with one’s comments about what is interesting about these points.

The second phase is to go back to the transcripts and identify small segments of data and then add some identifier to them, this is called *coding*. The codes can be descriptive notes, different coloured highlighters or pens, or if a specialist software is used, numerical identifiers. The identification of the type of interviewees selected was based on the institutions within the sociotechnical regime networks identified via the literature review and secondary published data. However, this data analysis is what is called ‘data-driven’ as opposed to ‘theory-driven’. This means that many of the groupings of information, i.e. the themes, that will emerge from the data should represent concepts in transition building which should enhance and add to the data that has already been extracted from the literature. The different method of ‘coloured highlighters’, and written notes were used to identify codes. Some sample interview texts are shown in Picture 4 below. When coding, it is important not to lose context by highlighting a bit of data and ignoring the context. This context may reflect on the knowledge base of the interviewee, which could explain a conflict within the data-set, as to why a different interview with a different knowledge base had an opposite opinion.



Picture 4 Example of highlighted texts and some of the codes

The third phase is to sort the codes to see how they may combine to form possible themes (Picture 4). It is also important to identify if the interviewees place any sequential information to what they said, i.e. how long a specific process takes to go through the system, or 'this must be done before that' for a transition to be successful. This helps to create a timeline and sequence for the transition under research. Within this phase importance or hierarchy should emerge, i.e. 'overarching themes' or 'sub-themes'.

The fourth phase is to review the coded data bits to make sure that they are coherent and form a true pattern that is a theme, or whether they may form a new theme or belong to a different theme. By the end of this stage all the themes should be formalised, and sequenced into a coherent narrative that 'tells the overall story about the data'. This sequencing of the themes is also known as a 'thematic map' of the data.

The fifth and sixth phases is to take this thematic map and start to write up each individual theme in detail, and to produce a report that aims to inform the reader 'of the merit and validity' of the analysis of the complicated subject being researched. It should make sense of the data not just paraphrase it. The narrative must go beyond the description of the data, and make a proper analytical discussion that deals with the research question. The narrative should not only tell a detailed 'story' about each particular theme, but also how the themes fit into the overall picture. Data gathering using interviews has its limitations as to how many

people can be interviewed, and what they say. Inevitably, especially when the interview data is correlated with the secondary data, gaps may be identified. Also what people ‘did not say’ may be just as important as what they ‘did say’ i.e. because for many of the interviewees electricity was not part of their knowledgebase how will/did they react to technical questions is important.

From the activity of coding the interview transcripts themes emerged. Once the themes were known, the methodology known as the ‘5Ws plus H’ was used to sequence them into the narrative of Chapter 5. The origin of this methodology is thought by Robertson (1946) to be an ancient Greek rhetorician called Hermagoras of Temnos, and is found in the poem by Rudyard Kipling called ‘elephants Child’ in his book ‘Just-so stories’ (1902). How the ‘5Ws plus H’ is reflected in the transition of this research is set out in Table 4.2.

Table 4.1 The ‘5Ws plus H’ problem solving technique.

<b>What</b> is this research trying to achieve and <b>where</b> is it trying to do it?
<b>Why</b> should such a transition take place?
<b>Who</b> will facilitate such a transition?
<b>How</b> will this transition take place?
<b>When</b> will it happen?

#### 4.6.6. Framing the transition using a timeline

Visualisation using a timeline (Karam, 1994) is a methodology that can be used to represent the stages, and sequence of processes, for the transition to distributed DC systems. It allows each stage or process to be assigned both a timeframe and a sequence. This research uses timeline visualisation to present a possible transition pathway/framework, for each of the processes that emerged from the interview data and over the five phases of the transition (see Chapter 6 below). The timeline will show at least one possible pathway for a transition to a society within which DC electrical systems can proliferate.

#### **4.7. Conclusion**

When looking at an historical case study and gathering information via interviews, there will be some aspects that will be objective concepts which can be relied upon, and some will include elements of subjectivism and/or of the interpretation and understanding of this researcher, as well as from the interviewees. It is therefore important to keep in mind that the data gathered for this research will be both objective and subjective (Holden and Lynch, , Figure 5, p. 9)

As this research is sociotechnical in nature it is mainly interpretivist knowledge (epistemology) based in nature due to the socio aspect of the research. The technology is an aspect of realism as it is a real world (Ontology) electrical system. This research uses sociotechnical systems and transition theory to understand the present electrical system. It uses qualitative data gathering methods with a mind to being as objective as possible.

This research, which is looking into the sociotechnical aspects of the use of electricity in the built environment, has therefore a large social scientific aspect. It employs a conceptual framework that was developed out of the theory called ‘the multi-level perspective on sociotechnical transitions’. It will use a single case (UK only) multi-method case study to gather data, consisting of secondary data and primary semi-structured interview data. In the nets chapter, the transcripts will be analysed using thematic analysis, and the 5Ws plus H methods. In Chapter 6, the transition pathway will be presented using a timeline that shows how each identified process is carried out over the duration of the transition.

## Chapter 5

# Data analysis for building a transition framework

### 5.1. Introduction

The goal of this research was to understand how the electrical system in the UK can transition from the incumbent AC electricity system to one where DC systems would proliferate. A literature search was carried out that identified the electricity system as consisting of social aspects, as well as the technical aspects, thus identifying the electricity system as being sociotechnical (see Section 2.2.7 above). The transition theory chosen was the multi-level perspective on sociotechnical transitions (see Section 3.2 above). The electricity system in the UK was chosen as a single case study and as printed information about many aspects of the electricity system was available, a multi-method single case study technique was chosen to gather data (See Section 4.6). The initial data was gathered from secondary sources to identify what the sociotechnical aspects of the electricity system were (Section 2.2.7). From this, the social networks that make up the sociotechnical electricity system in the UK, were identified (Section 3.3.9).

The question then arose: how do these networks operate internally and what are the interactions between these networks i.e.: what is the internal and external structuration of the social networks within the sociotechnical electricity system? (see Section 3.2.6). Furthermore, a transition to DC systems will imply changes across many if not all of these social networks. Therefore, what are the individual transitions within these social networks that must combine together to provide the whole transition for a transition to DC to be successful i.e. what is the transition framework for AC to transition to DC? To answer these questions, the second stage of data gathering was carried out using targeted interviews. The interviewees were chosen so that at least one reputable representative could be interviewed from as many of the social networks identified in Figure 3.6 as possible. It was important that they would be able to explain how processes of change occur within their institutions and how a transition to distributed DC electricity would impact or be impacted by their organisation. A set of generic questions was compiled that would be about the internal and external structuration of these institutions (Section 4.6.4). The generic questions were then modified to be more targeted to

the expertise, knowledgebase and job description of each interviewee. Some of the questions were focused on gleaning their thoughts and opinions as to what elements they thought were required for this transition to take place. Therefore, each interview was of a semi-structured nature.

The interviews were transcribed and using thematic analysis (see Section 4.6.5) the data was analysed. Points of interest were highlighted and then a code was attributed to each highlighted point. Through manual means, the codes were grouped into themes. The theoretical framework influenced who was interviewed and what core questions were asked, however, it only shaped some of the themes, overall it was from the interview data that these themes were developed. In this chapter, the eight themes that have been identified will be discussed and relevant points that form part of the overall transition will be highlighted. Once the themes were known, the methodology known as the ‘5Ws plus H’ (Robertson, 1946) was used to sequence them into the narrative of this chapter, from which a generalised transition framework will be developed in the next chapter. How this technique is associated with the themes is shown in Table 5.1 below.

Table 5.1 How the themes are associated with the ‘5Ws plus H’ problem solving technique.

<b>The ‘5Ws plus H’ problem solving technique</b>	
<b>What</b> is this research trying to achieve and <b>where</b> is it trying to do it?	W1: A transition of the electricity system from AC voltage to DC voltage. W2: in the UK
<b>Why</b> should such a transition take place?	W3: What are the intellectual discussions surrounding such a transition?
<b>Who</b> will facilitate such a transition?	W4: Who does one have to bring on-side to help facilitate such a transition?
<b>How</b> will this transition take place?	H: How will the transition happen, i.e. what are the individual actions needed to assure a successful transition?
<b>When</b> will it happen?	W5: What are the individual time-frames for each set of actions that make up the transitioning process? How long will the transition take?

## 5.2. About the Interviewees

The interviewees were chosen for their expert knowledge and positions in industry, policy making and research and for their ability to understand a part of the process through which the transition from AC to DC will have to go through. The initial interviewees were approached at a special launch workshop for the IET's DC Code of Practice, this was followed by some interviewees from a conference on sustainability and policy making. These interviewees provided names of other possible interviewees some of whom became the next few interviewees. The remainder of the interviewees were approached due to having authored relevant articles or were featured in energy and engineering magazines. In total 20 interviewees were carried out. Three potential interviewees agreed to do an interview, but finally declined because they were not able to commit the time. The interviews were based on a targeted set of questions as described in Section 4.6.4, which were modified with follow up questions depending on their background and job description, thus following a conversational strategy. Many of the UK's manufacturers of home appliances were approached for interviews, but they all either declined or never acknowledged the approach, they are therefore underrepresented in this data.

All the interviews were carried out over the telephone. They were all digitally recorded and a full transcript was prepared. Together with the questions the interview data came to 116,261 words. A profile of the experience and work of all 20 interviewees is given in Table 5.2 below. All these people were influential within their sphere of expertise, with many in advisory roles to energy policymakers.

Table 5.2 Profile of the 20 interviewees.

<b>Institution</b>	<b>Organisation</b>	<b>Background</b>	<b>Work and Experience</b>
Research	Technology Strategy Board the Knowledge Transfer Network	Electronic Engineer	Principally responsible for community building and knowledge dissemination
User	IT department of a Bank	Engineer	Principle involved in scoping for DC project
Trade Association and Standards	Standards	Engineer	Was chief executive of a Chartered Institute, Chairman of a Standards Working Group
Manufacture and installer	Manufacture and installer of DC home	Engineer	Chief Technology Officer



<b>Institution</b>	<b>Organisation</b>	<b>Background</b>	<b>Work and Experience</b>
	systems		
Intellectual Property and Consultancy	Consultancy	Electrical Engineer	Chief executive, fellow of the IET
User	University	Professor of Electrical and Electronic Engineering	Director of a unit within the University with 30 years of experience
User	University	Senior Lecturer in Electrical and Electronic Engineering	Lecturer and research investigator for DC project
Research	Postdoctoral researcher at university	Engineer	Research fellow looking at trends in power consumption
Manufacturer	White goods and home appliances	Engineer	Expert responsible for all parts of a dishwasher
Trade association and standards	Association of Manufacturers of Domestic Appliances	Lead Engineer	30 years' experience with standards, technical manager for organisation, on standards committees including the IET Wiring Regulations
Consultancy-energy	Private Consultancy	Engineering Professor. Electrical power systems engineer	30 years in big network companies, specialises in smart grid technologies, on advisory board to UKERC, member of the IET energy policy panel
Research	Professor in energy research and teaching	Engineer	Energy modelling and energy systems, integrated energy systems
Funding body	Engineering and Physical Sciences Research Council		Dealing with funding rounds and proposals within the area of the built environment
Funding body	Research Councils UK		Head of Strategy Unit
Consultancy	A sustainability institute	Economist	Visiting Professor, works in areas of sustainability and climate change, fragile states and governance, worked on the Stranded Assets Program

<b>Institution</b>	<b>Organisation</b>	<b>Background</b>	<b>Work and Experience</b>
Energy policy	Think Tank	Politics and Economics	Energy policy, sociotechnical transitions
Director of a national body	Senior research fellow	Politics, Philosophy and Economics	Senior research fellow, energy policy, innovation, governance, sustainability, focuses on politics and governance, expert on relationships between policy, institutions and lobby/pressure groups
Policy	Parliamentary Office of Science and Technology	Anthropologist	Science advisor to parliamentary committees, executive director of the Centre for Science and Policy
Standards	Building Research Establishment	Chemistry and materials engineering	20 years' experience in the energy field on standards committees
Regulatory authority	Ofgem	Green Chemistry	Has many years of experience in sustainability, energy policy, future energy systems

Besides the difficulty in getting the interviewees, some of them had preconceived notions about distributed energy systems and the concept of using DC voltage, which introduced some difficulties into the interview process. For example, when asked could the current building management systems be used in the home, the answer was *“You don’t need them domestically, so it is an irrelevant question”*. In addition, when asked if off grid electricity systems could help towards energy security or energy independence one engineer answered *“This is my personal view, small-scale renewables are a complete waste of time”*. This is in contrast to interviewee 10 who was asked if it is possible to transpose the National Grid smart grid technology to make it small scale for the home, he responded: *“yes I did this in my Ph.D.”*. Many of the interviewees who were not engineers were not conversant with the electricity system and felt that electricity was not their subject and were unable to answer any related questions. As such some of the interviews from the engineers and non-engineers were difficult and at times challenging. The discussion around the advantages or disadvantages of AC verses DC electricity systems was answered by the engineers from the technical rather than sociological point of view. However, some, through direct questions about energy

security and independence and the usage of distributed DC systems for the developing world, opened up to a non-technical discussion.

### 5.3. Methodology for data analysis and coding

As explained in chapter 4, the methodology used to analyse the transcript data is based on the six stage process for thematic analysis as is described by Braun and Clarke (2006) (see Section 4.6.5). It was thought that the theoretical framework and the social networks developed in Chapter 3 would inform about possible themes that may emerge from the data. However, as will be shown, only one theme ‘*technology*’ emerged from Braun and Clarke’s thematic analysis, which corresponded to the technology network that emerged from the institutional analysis in Chapter 3. The coding was carried out manually with the codes being developed as the reading took place. Nineteen codes were generated from the reading of interview 1, five more from interview 2 and only two from interview 3, the rest of which were distributed across the other transcripts. A total of 42 codes were generated which are set out below in Table 5.3.

Table 5.3 The codes and their associated themes.

#	Theme	Code	Meaning of code
1	7	K	Knowledgebase of interviewee
2	4	F	How things are funded, routes to funding, funding mechanism
3	5	C	Community building, team building
4	5	spC	Special interest groups (part of community)
5	2	G	Bridging the gaps in the technology lifecycle
6	4	F <sub>DP</sub>	Funding body’s delivery plan to which any new technology must align itself
7	8	T	Time dependence: 5-year plan, 6 months funding process
8	5	S	Scoping (how is this done)
9	6	S <sub>P</sub>	Specialisation within institutions (1) sector (2) sub-sector
10	5	T <sub>CH</sub>	Technology champion
11	6	P <sub>CH</sub>	Process of change
12	2	TA	Technology alignment to delivery plan
13	5	CW	Comprises the whole community
14	6	K <sub>T</sub>	Knowledge transfer out of institution
15	4	S <sub>T</sub>	Standards
16	1	B <sub>DC</sub>	Barriers for DC
17	1	E <sub>DC</sub>	Enablers for DC

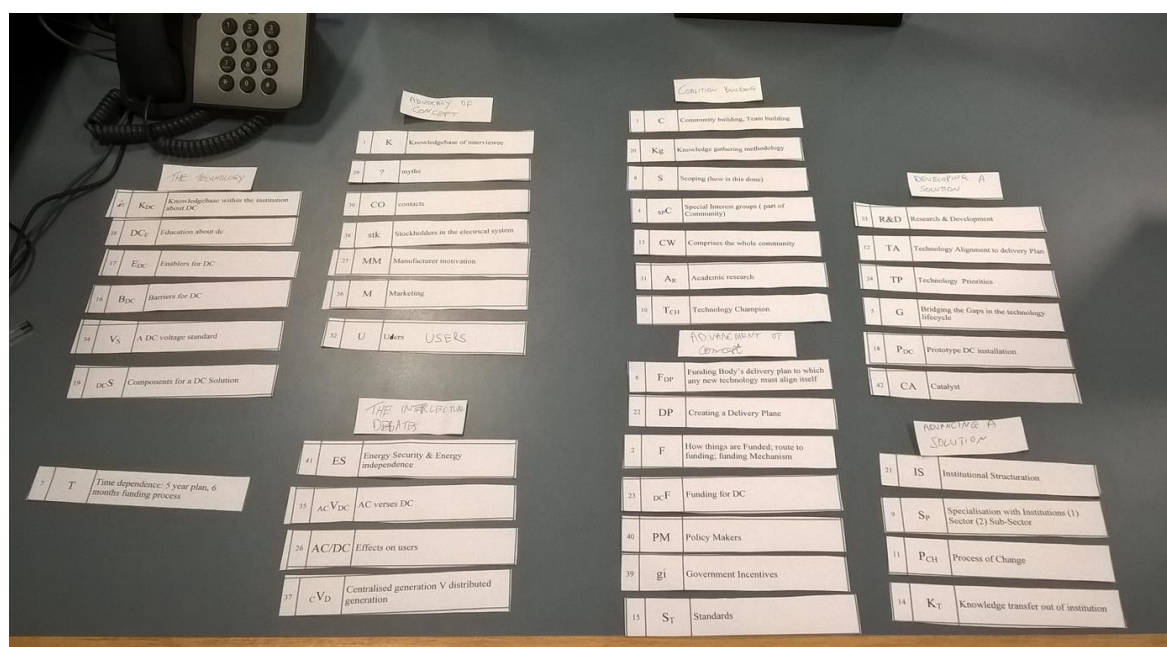
#	Theme	Code	Meaning of code
18	2	P <sub>DC</sub>	Prototype DC installation
19	1	DCS	Components for a DC solution
20	5	K <sub>g</sub>	Knowledge gathering methodology
21	6	IS	Institutional structuration
22	4	DP	Creating a delivery plan
23	4	DC <sub>F</sub>	Funding for DC
24	2	TP	Technology priorities
25	1	K <sub>DC</sub>	Knowledgebase within the institution about DC
26	2	AC/DC	Effects on users
27	7	MM	Manufacturer motivation
28	7	DC <sub>E</sub>	Education about DC
29	7	?	Myths
30	7	CO	Contacts
31	5	A <sub>R</sub>	Academic research
32	7	U	Users
33	2	R&D	Research and development
34	1	V <sub>S</sub>	A DC voltage standard
35	3	ACV <sub>DC</sub>	Ac verses DC
36	7	M	Marketing
37	3	cV <sub>D</sub>	Centralised generation v distributed generation
38	7	stk	Stakeholders in the electrical system
39	4	gi	Government incentives
40	4	PM	Policy makers
41	3	ES	Energy security and energy independence
42	2	CA	Catalyst

#### 5.4. Themes

After the coding was finished each code was printed out and then they were manually sorted (Picture 5 below), to see if any grouping of codes would bring out some themes. Once a set of themes was identified, Table 5.5 below, the ‘5Ws plus H’ technique was used to put them into a narrative. The actual names for the themes were changed as the narrative became clearer. The themes are set out below in Table 5.4

Table 5.4 The eight themes that represent the constituent parts of the transition process.

Theme	5Ws + H		The Themes
1	W1, W2	What, Where	The technology in the UK
2	W3	Why	The intellectual discussion
3	W4	Who	Coalition building
4	H1	How	Developing a niche technology
5	H2	How	Second stage project development
6	H3	How	Advancing a solution
7	W4, H4	How to deal with Who	Advocacy of a concept
8	W5	When	Time dependence



Picture 5 The sorted codes used to formulate the themes.

Each theme was given a number that loosely represents the sequence of processes needed for a transition to take place. However, it is obvious that within each theme the components develop and expand as the process of transitioning develops. Some of the codes are generic across many themes, for example funding and research, which takes place at multiple stages of the transition (see Figure 6.4). This means, that as the narrative was extracted from the interview data, the collated codes were moved to the next appropriate theme and read again.

Table 5.5 The codes in each theme.

W1	What	Theme 1	H1	How	Theme 4	H4	How	Theme 7
Code No	Code	The technology	Code No	Code	Developing a niche technology	Code No	Code	Advocacy of a concept
16	B <sub>DC</sub>	Barriers for DC	5	G	Bridging the Gaps in the technology lifecycle	1	K	Knowledgebase of interviewee
17	E <sub>DC</sub>	Enablers for DC	12	TA	Technology Alignment to delivery plan	27	MM	Manufacturer motivation
26	AC/DC	Effects on users	18	P <sub>DC</sub>	Prototype DC installation	29	?	myths
19	dcS	Components for a DC Solution	24	TP	Technology Priorities	30	CO	contacts
25	K <sub>DC</sub>	Knowledgebase within the institution about DC	33	R&D	Research and Development	32	U	Users
34	V <sub>S</sub>	A DC voltage standard	42	CA	Catalyst	36	M	Marketing
						28	DC <sub>E</sub>	Education about DC
38	stk	Stockholders in the electrical system						
W3	Why	Theme 2	H2	How	Theme 5	8	When	Theme 8
Code No	Code	The intellectual discussions	Code No	Code	Second stage project development	Code No	Code	Time dependence
35	ACV <sub>DC</sub>	AC verses DC	2	F	How things are Funded: route to funding: funding Mechanism	7	T	Time dependence: 5-year plan, 6 months funding process
37	cV <sub>D</sub>	Centralised generation V distributed generation	6	FDP	Funding Body's delivery plan to which any new technology must align itself			
41	ES	Energy Security and Energy independence	15	S <sub>T</sub>	Standards			
			22	DP	Creating a Delivery Plane			
W4	Who	Theme 3	H3	How	Theme 6			
Code No	Code	Coalition building	Code No	Code	Advancing a solution			
3	C	Community building, Team building	9	S <sub>P</sub>	Specialisation with Institutions (1) Sector (2) Sub-Sector			
4	S <sub>IP</sub>	Special Interest groups	11	P <sub>CH</sub>	Process of Change			
8	S	Scoping (how is this done)	14	K <sub>T</sub>	Knowledge transfer out of institution			
10	T <sub>CH</sub>	Technology Champion	21	IS	Institutional Structuration			
13	CW	Comprises the whole community						
20	K <sub>g</sub>	Knowledge gathering methodology						
31	AR	Academic research						

## 5.5. Theme 1 - The technology – W1

Please note, all quotes that are taken verbatim from the interviewees are italicized between quotes and any relevant points that will be discussed in more details in the next chapter or are of interest for further work are in **bold**.

This research, which is about a sociotechnical transition, has technology at its heart, which is the '*what*' of the transition (W1), i.e. what is transitioning is the technology of the electricity system. One of the social networks, from Chapter 3, is the actual technology that makes up the electricity generation, transmission and consumption systems. The theoretical model therefore fed into the questions asked to the interviewees that revolved around what they knew about AC and DC electricity systems. Their opinions, about possible enablers and barriers as well as how their institution may be effected by a transition to distributed DC electrical systems, were sought. Therefore, having technology as a theme was expected from the theory. The interviewees discussed the following: their personal knowledge about the electricity system, how to transfer knowledge about decentralised DC electricity systems and what they saw as any advantages, disadvantages, barriers and enablers for a transition to occur.

### 5.5.1. Knowledge about DC and knowledge transfer

All the interviewees were asked what they knew about DC voltage systems and besides the engineers who are practitioners in the field, most knew very little to nothing. On one hand this is what was expected as their backgrounds and expertise was not in the fields of science or engineering. However, as they were all experts in responsible positions within the field of energy and sustainability **one has to question whether this skew in the knowledgebase causes a bias within the solutions they provide**. When it was pointed out that solar panels generate DC voltage and that all electronics consume DC power and that there is a two-stage transformation from DC to AC and AC to DC, there was some recognition that DC could have potential advantages over AC. Some interviewees pointed out that as far as consumers, including most politicians involved with energy policy, are concerned they neither know nor

care if the electricity system is AC or DC, all they want is that when they plug in an electrical appliance it works.

As interviewee 6 put it;

*“Do people really care if their power is AC or DC, the answer is no, as they either don’t know or couldn’t care less. What users care about is if they come home with a new device, can it be plugged straight in and used with the electrical system in the home, that would apply whether it is in the African bush or in West Hampstead.”*

Similarly, interviewee 9 stated that:

*“We went into the librarian of Management and Social Sciences, if you say AC/DC you think of a pop group, they could not care less if is AC or DC all they wanted is quality of service and we were able to deliver a better quality of service than from the AC system.”*

Even graduate electrical engineers, although they are taught the basic engineering principles of AC and DC applications, for example about different types of motors, they do not understand the technical challenges associated with DC electricity systems. Interviewee 9 explained as follows:

*“We need engineers who understand what’s going on and a significantly and embarrassing high proportion of our graduates in electrical engineering have very little understanding about the real problems in electricity supply, I am heavily involved in undergraduate and postgraduate education both taught and by research and it is a revelation when I introduce some of the simple concepts...”*

Interviewee 3 explained the reaction to his suggestion to introduce DC voltage systems into his company:

*“There is some resistance from various people who think that we are not going in a forward-looking way we are looking backwards but that is because they don’t understand the technology and the options that are available to us at this time.”*  
He also said that *“...technology awareness is a big bottleneck in terms of being able to convince others that a step change from AC to DC is achievable...”*

Many electrical engineers appeared to have ‘technical lock-in’ (see Section 3.2.7), to AC electricity and see no reason to change. Some of the electrical engineers were asked questions associated with social reasons for change, such as energy independence, energy security, city resilience etc. Some of them while not totally convinced showed some appreciation for these non-technical reasons for such systems, but some were not. Interviewee 20 dismissed these



‘socio’ reasons as ‘second’ or ‘third’ order reasons and therefore of no concern to the engineering world. Some of the interviewees were lead researchers within think-tanks and consultancies that primarily deal with sustainability and energy policy, yet they not only knew nothing about electrical systems, they said that no one in their organisations had any engineering expertise. All the engineers interviewed were asked if they knew if the carbon footprint of AC electrical systems was more or less than that of DC equivalent systems and they all said they did not know, including those that implemented DC systems. Asked if they knew if anyone is doing research in this field they also stated that they did not know. However, interviewee 20 stated that the actual system was smaller. **Therefore, there is a need to do more research in comparing the carbon footprint of AC and DC systems.**

Asked if equivalent AC and DC systems use more or less energy, conflicting answers were given. Interviewee 15 stated that large DC motors use up more energy than AC and interviewee 10 stated the same for power over Ethernet, while interviewees 8 and 9 said that their DC system saved energy compared to the AC original system. **Therefore, more research needs to be carried out to see if across all electrical and electronic devices AC or DC uses up more or less energy.** Perhaps this new research will agree with these interviewees that it will depend on the design and type of the technology as to which system will use up less energy. Also many of the interviewees either knew nothing or very little about the association of energy security and energy independence with decentralised electricity systems. These are therefore areas for **further research.**

When a challenge is seen within a wider context, it is easy to understand that a barrier can be contextualised as the other side of the coin as an enabler. So while the lack of knowledge about electricity in general and distributed DC voltage systems in particular among many professionals is a barrier to transitioning to DC, herein is highlighted the first enabler. **For professionals to take up a transition to DC they will need to understand and appreciate the whole sociotechnical picture of the energy and electricity system.**

Knowledge transfer between, the soft subjects from the social sciences and arts and the engineering fraternity, have been highlighted by many interviewees as a major barrier. An interviewee stated the following:

*Q: "Would you say that in the sector in which you operate i.e. consultancies think tanks etc. that deal with policy, how strong to you think electrical engineering skills are?" A: "They are mostly absent to be honest, it is a pretty small world and I know pretty much everyone working in the London based policy world, there are few people in there that maybe have an engineering background. Most people have the social, economic and political backgrounds, it would be useful, but what I said is because these are policy discussions, you need engineers to understand the politics about what we are talking about and not just the technical options".*

*"I think there definitely is a big gap there. I mean, we are relatively limited in what we can do because we are a policy think tank, so the people that staff the organisation are generally people with a policy background and that is largely socially based. However, we are working in a very technical area, where getting your head around the different options for moving to a sustainable low carbon energy system requires a reasonable level of technical understanding, having some engineering in that would be fantastic, but we can't just employ an engineer solely for doing that, they would also have to understand the politics of what we are doing so where we sit is that we try to translate the technical information to a political audience, so having an engineer speaking engineering speak, wouldn't really help us as what is needed is someone that can translate it."*

Engineers might be viewed as problem solvers and according to interviewee 19:

*"...and unlike the social sciences there is not a lot of time for debate and discussion and wider reading and all that kind of stuff at undergraduate level. There is not a lot of debating and I think there is a big gap here. What I think happens is that the engineers don't speak up and the engineers don't get a voice and there are very few engineers who get the attention of the media..."*

I.e. engineers have not been given the time throughout their training to actively get involved in debating and discussing the ramifications of their output. This he continued is why they are not in the forefront of the global energy debate, a debate dominated by social science and business and finance experts. He therefore suggested that the beginning of knowledge transfer should begin in school and be part of all undergraduate engineering, social science and business and finance degrees. Bridging the knowledge gap between these two academic fraternities should be a pathway for more co-operation and therefore better solutions for the 21<sup>st</sup> century's global issues.

An interviewee who used to work for a multinational NGO within the sustainability and climate change fraternity lamented that many NGOs:

*"...do not have much influence on government because they are not coming up with credible alternatives, in my view, what the NGOs are doing is disagreeing*

*with things but what they really need is solutions.”, “...they are becoming increasingly irrelevant”.*

He therefore suggested approaching these NGOs about the merits of using distributed DC electrical systems thus providing them with a credible solution from an engineering perspective.

The social scientists are convinced that ‘engineering’ is not their subject and engineers do not see the social ramifications of their engineering output of utmost importance. **Therefore, the understanding and technological awareness of the social scientists about the whole electricity system and the lack of interaction of the engineers with the sustainability and policy debates, are seen as huge knowledge gaps by this research and because the interviewees are in positions of influence this can be a barrier for the transition to DC.**

### **5.5.2. The economics of DC voltage systems**

For almost all the interviewees the idea of using distributed DC voltage systems to provide the electrical power in the home was a completely new idea. They therefore acted as protagonists and asked questions about how such a system would work. One of the things that concerned them was the economics of DC systems. Given that the UK already has a national grid system, by introducing DC systems they envisioned two problems. The first is: if the DC systems are connected to the national grid, then the problem of balancing the grid due to the intermittence of solar and wind generation will be exacerbated by an increase of such systems. As interviewee 18 put it:

*“...PV has a huge lack of inertia about it, so when a cloud comes over it can drop off tens of percent of power doing it on a half hourly basis or on a second by second basis, is seeing huge fluctuations in power across the system, so all those parties would have to be interacting on a second by second basis, but on top of all that is that you have the difference between summer peaks and winter troughs and that might be the effect of between hundred percent and zero. So given in winter you have suddenly gone to a situation where your security of supply looks quite different than it does today, you know because you in effect cannot give any firm capacity to that photovoltaics, even though you might get 10% of power out of it over the winter, at any given time, it might be zero.”*

The second problem highlighted by interviewees 11 and 19, was what has been called ‘stranded assets’ (Caldecott et al., 2014; Lucas, 2016). Billions of pounds have been invested

in a working AC centralised system, so why would anyone want to make it redundant and move to a distributed DC system? For these reasons interviewees 1 and 14 stated that DC would never replace AC. However, when asked about the use of distributed DC systems for the 1.4 billion people who in 2012 did not have a connection to a national grid and therefore possible export benefits for UK PLC from any new DC technology, many opened up to the possibility that such a system may have its place. It was pointed out that just like some developing countries sidestepped analogue telephony and went straight to mobile technology (James, 2016) so too they may sidestep centralised electricity generation and go direct to distributed systems. Interviewees 8 and 19 saw such a system as part of a hybrid system, whereby AC and DC exist together in the home, especially within new build homes. Interviewees 15 and 16 saw loads of between 1000 and 3000 Watts as being a barrier to the usage of DC at extra low voltage. **Therefore, if a way could be found to re-engineer appliances so that they could be powered from renewables, then this would be a catalyst for DC systems to take off especially in the developing world.**

The economic advantages for using DC systems were stated by interviewees 8 and 9. They stated that there was a reduction in capital cost for the system; that it took less time to implement; that since backup was used the system was resilient in the face of blackouts and less parts were needed; that the DC system was therefore more scalable; the elimination of 3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup> order harmonics associated with AC computer networks saved energy. Interviewee 20 who was not involved in actual DC installations, but is a professor of electrical engineering stated that the savings are so minimal that it is not worth the transition. Interviewee 5 stated that *“AC to DC power supplies are becoming increasingly efficient. The cost benefit analysis just makes it not worthwhile, that is much more likely to kill DC than a lack of research”*. Interviewees 5 and 10 stated that modern AC to DC converters which use switch mode power supplies are up to 97% efficient and interviewee 5 stated that *“...you certainly need a Max Power Point Tracker and something to manage the battery system, which cost the same as an inverter...”* i.e. the electronic kit needed to manage the voltage in a full DC system is still needed together with DC to DC converters. **Therefore, due to these conflicting claims more rigorous bench testing will have to be carried out, using scientific methodologies, to compare and contrast the economics of AC and DC systems.**

### 5.5.3. DC voltage for domestic application

The usage of DC electricity within the home or to power a home is as old as the AC electricity system itself. Interviewee 6 remembered the round pin plugs and having DC electricity in his home when he was growing up. He also pointed out that the shutters on the wall sockets, were not as commonly thought, put there to stop children getting electrocuted, but they go back to the 1920s when these shutters were to deal with arcing of the electricity when the plug on a DC voltage system was removed. It was also pointed out by interviewees 5, 6, 11 and 12 that as more electronics is being used the future trend will be more towards using DC voltage. Interviewee 5 explained why his company developed his DC products because:

*“...effectively electronics are DC and we were interested in more efficient and lower cost ways of powering all the DC things that we have in the home”.*

The main barriers to proliferation of DC within the house is the lack of academic research in the area of domestic DC voltage, however there is the IEEE 802.3 standard (IEEE, 2012) for Power over Ethernet (PoE). Many of the engineers interviewed saw this as a catalyst to embedding DC electricity supply into the built environment. While most saw PoE as a catalyst for a low powered DC system to supply LED and electronics in the office they could not envision a DC house that requires high powered devices, i.e. over 1000 Watts, ever being powered via Ethernet cables. There is also the USB Power delivery standard that can provide, via a USB 2 or USB 3 cable, 5 Amperes at 20 Volts, which is also a 100 Watt power supply. Interviewee 5 stated that there is a need for the USB standard to be adopted as a power delivery standard for mainstream products to drive the adoption of DC in the home:

*“...if that really takes off as the USB consortium hope it will, that will have a dramatic effect on the ability to provide DC power to lots of DC devices in the home.”* He went on to say that *“I am confident that we will see this USB power standard taking off and it will become the standard way things are powered and that will mean that we will see a lot of devices that are powered by DC sources. I think the DC ring main or DC distribution is much less certain. We obviously think it’s a great idea”.*

Interviewee 10, who discussed Power over Ethernet (PoE) as a catalyst and means of proliferating DC applications in homes, pointed out that it has a nominal voltage of 55 V, which is usually 48V at the socket and a maximum power of 100W. He concurred with

interviewees 5 and 16 that USB will only be for very low power devices and will never be able to replace the 240AC ring main.

Only interviewees 5, 8 and 9 out of 20 interviewees had hands-on-experience of DC bespoke domestic systems and were therefore able to discuss the voltage level for domestic DC electricity. One, a manufacturer of low powered domestic DC systems for IT and lighting that can easily be retrofitted to homes, stated that he was “agnostic” about a voltage level for DC. The other interviewees were leaders within ‘Project SoLa Bristol’ which is 30 houses in the north of Bristol which have a DC micro-grid installed into them (Kaushik et al., 2014). The electricity comes in to the houses as AC and is transformed down to 24V DC to run low power DC devices. The reason why 24V was chosen as the voltage level was because “...that is what is available on the commercial market...” and “...industry tends to stick with what it knows...” (interviewee 8), i.e. commercially available DC appliances work on 12V and 24V DC (RoadPro, 2016). No one interviewed was in favour of the US Emerge Alliance standard of 380 to 400 V DC for usage in homes. No one envisioned high-powered appliances running on DC in the near future. However, interviewee 15, an expert in domestic appliances, stated that for a dishwasher that is usually rated at 2500 Watt and above, if it was possible to put into it hot water and therefore remove the heating element from within the appliance, then the wash cycle could operate at below 200 Watts, which would make it an ideal low power appliance easily powered by DC voltage. **Therefore, re-engineering home appliances to operate at extra low voltage is a possible avenue for further research.**

#### 5.5.4. What knowledge is lacking?

Interviewee 3 stated as follows;

*“We have a considerable amount of chartered electrical engineers but we don’t have anyone with any experience of DC power distribution so we again need to re-educate those people in what DC actually is, how it actually distributes, how it generates what components are involved so we are at the point where knowledge is low and the aspiration for DC is low but the technical competency of the individuals is quite high, so it wouldn’t take too long for the people that we have, to understand DC technology and move on quite quickly I would say about 12 months.”*

This was further corroborated by interviewee 5 who was asked “What level of knowledge for DC do electrical installers have at the moment? Answer “*there is none*”. He was further asked: In order for them to install your systems what training process do they have to go through? He answered: “*We give them a one-day training process they need to be a part P electrician and then we explain to them where in the electricity regulations we are sitting, how it is being installed and it is basically about where it sits within existing building codes, as opposed to anything new.*” It was therefore agreed that electrical engineers are proficient but that they lack the knowledge about design, commissioning, implementing, testing and certifying of extra low voltage DC systems, i.e. less than 120 V DC. The same was said about electricians. There is also a lack of off the shelf test equipment for extra low voltage DC systems. However, as stated, those few who are involved with implementing DC systems pointed out that the electrical engineers and the electricians had a short and smooth learning curve to gain these competences. **This therefore implies that the learning curve for future DC installation engineers should be short and smooth.**

#### **5.5.5. Barriers to proliferation of DC electrical systems**

Getting planning permission for rooftop PVs was seen by interviewees 9 and 14 as a barrier for DC. During the interviews it was mentioned that in the UK some of the buildings are listed and some houses have thatched roofs, making rooftop PV systems unavailable (interviewee 16). Furthermore, one university turned down the use of PVs on ‘*visual grounds*’ (interviewee 9) i.e. they were seen as an eyesore. Therefore, not every building can have PVs on the roof. To circumvent some of these problems, some PVs are made to simulate roof top tiles and are made to be fitted in-line with the tiles rather than on top of them, as part of what is called building integrated PV (Cekić et al., 2015; Tripathy et al., 2016). Interviewee 19 saw housebuilders as being a barrier to DC unless there will be a statutory obligation on them to install PVs. This is because it adds to their construction costs that cannot be passed on in a higher sales price for the home, especially if they are building ‘affordable’ homes. It was pointed out that it would need mandatory requirements before housebuilders would put PVs on every house.

An interesting point came out about the complex issues surrounding energy policy and the issue of retrofitting UK homes, which according to a Guertler et al (2015) rank as one of the most inefficient housing stocks in Europe. As interviewee 17 put it:

*“There are people within the debate who are forward-looking enough to work with engineers to understand those different options, but there is also a very real kind of ground-war at the moment happening about whether we can afford to do anything, even with your low-cost technology like solar panels and onshore wind, whether we can start to roll storage out, whether we could just put cavity wall insulation into homes, a bit of loft insulation, really low-cost things, we are having a really big fight at the moment, whether even that is possible. So I do agree with you that there is a need to include engineering expertise within it, but we also need to be realistic, at the moment, the people who make decisions are fighting over the money, they’re not fighting over technology”*

A further interesting point was brought up by interviewee 19 with regard to the governance of the whole electricity system:

*“The IET looked at other industries and the other industries all said “we have the role of a Systems Architect”. The architect may be looking across the architecture of a modern large aeroplane, they don’t own any of the assets and are not specialists in engines or cockpits, but the system architect ensures end to end joined up thinking, commonality of data and all that kind of thing, so it is an integration and holistic design role. So if you ask whose job is it in the power systems, the answer is nobody. So that is a huge gap and I am pleased that the IET is engaging, it has taken two years, but we are making progress and the government has agreed to fund an industry consultation about the need for change to what is called technical governance of the industry and arguably the case for some kind of systems architect.”*

#### **5.5.6. The main issues from this theme**

The main issues that come out of this theme are as follows:

1. Knowledge about the technology used in electricity systems among influential people within the energy and sustainability debate appears to be inadequate and understanding of the social aspects and energy policy by engineers is weak. Engineers are very much under represented within the energy and sustainability debate. Therefore, in order to bring joint up thinking about ‘whole systems architecture’ to the forefront of the energy debate, engineers must become engaged with policy and policy makers must become engaged with engineering concepts. This must be done for a successful transition to DC systems.



2. Current knowledge about DC electrical systems is a barrier to proliferation, but education starting from school and going through university can overcome this barrier. This is further discussed in the 6<sup>th</sup> Theme below. This should lead to a change in the prevailing thinking of DC in the eyes of electrical and electronic engineers.
3. There are already two usable low power energy networks that could help in the transition from AC to DC. These are Power over Ethernet and Power over USB, these will be discussed below in theme 2, 4 and 7. However many see these networks only as part of a hybrid house and not for a full DC home.
4. Due to conflicting claims about the advantages of using distributed DC systems, more rigorous bench testing must take place using scientific methodologies.
5. The new DC voltage house that employs smart technology as in the ‘Internet of Things’ must have an overall ‘*Systems Architect*’, a job description that does not exist for this type of domestic electricity system.

Before the interviews, secondary data had given us the social networks but had not given the institutional structuration within and between the networks. This theme has tentatively begun to show the connections between the networks. It has begun to join the research, societal, user, supplier and policy networks, via cross-disciplinary knowledge dissemination, education and for the need for someone to take ownership of the whole system in the form of a systems architect. The above points brought out within this theme are stages within the transition process to DC. These also corroborate the theoretical analysis provided at the end of Chapter 3 that the MLP, as it stands, is of a too higher order tool to incorporate all these details and for a transition to be properly understood, institutional structuration on the level of individual actions by actors, must be understood.

## **5.6. Theme 2 - The intellectual discussions surrounding DC electricity – W3**

This theme is W3, **why should the transition take place**. In general, four discussions emerged from the interviews. The first was about centralised generation and distribution verses distributed generation. Secondly, even if distributed generation has advantages over a centralised topology, why should the electricity system within the built environment be DC voltage, why can it not be AC? Thirdly, what is the role of the utility company in the

proliferation of distributed DC systems? Fourthly what was the meaning and importance to the interviewees of ‘energy security’ and ‘energy independence’? These discussions were deliberately part of the questions asked to the interviewees, as they had emerged from the literature review in chapter 2. This theme seeks to explore these discussions surrounding this research through the eyes of the interviewees.

### **5.6.1. Centralised or distributed generation**

The components and topology of both the centralised and distributed, (islanded or off-grid) electricity systems are shown above in Section 2.2 above. There are two distributed topologies, one where the building is not connected to any other building and has the capacity to provide its own electricity. The second is where the building is connected to other buildings and is perhaps reliant on electricity generated at a different location. Small or localised grids are still classified as distributed as they are not connected to a large national grid. However, this research still classifies grids with a single generation system even if they are not connected to a national grid as centralised systems as there is only one point of connectivity to many points of consumption.

Some of the interviewees were uncomfortable with a completely off grid electrical system, i.e. one that was completely independent from their neighbours. They wanted a distributed generation system, as it provides system resilience and security of supply against centralised power cuts, yet at the same time they wanted their houses to be interconnected to their neighbours so that they could trade energy and that their neighbour could act as a backup system if their own system failed. As interviewee 18 put it;

*“...so if there is any point of failure in your own house, if you are not connected to anyone else’s house, then you’re off grid for electricity. As a consumer I might feel that I’m not quite sure why I would go to that system.”*

Interviewees 10, 12, 17 and 18 were worried that if many distributed intermittent generators are connected to a grid system it would be harder to balance the centralised system. There is a common theme within the renewables discussion (Lamont, 2008; Parliamentary Office of Science and Technology, 2014b; Skea et al., 2008), that system security becomes harder to maintain when too many intermittent renewables are connected to the centralised system. Interviewee 18 provided a solution whereby local generation will be connected to a local grid

thus forming microgrids. Each microgrid can themselves be as far as possible self-balancing, thus reducing the interconnecting points between the centralised grid and the renewable generation thus reducing the present pressure on the grid from intermittent generation.

Interviewee 19 pointed out that while there is a trend towards a decentralised system using PVs, he still sees the future need for a national transmission grid for “*bulk power*” and for the imports of electricity from the continent. The prevailing energy policy is about smart grids, smart meters, the ‘internet of things’ and demand side management (Ofgem, 2010; Parliamentary Office of Science and Technology, 2014a; Strbac, 2008), which all provide inbuilt lock-in mechanisms for the prevailing centralised system.

The policy in 2015 favours centralised midscale PVs in solar parks and wind turbines in offshore wind farms, over local rooftop generation (Department of Energy and Climate Change, 2014b). This means that renewable generation is seen within the context of the centralised system, which itself requires capital investments to modernise, thus reinforcing the centralised topology of the electricity system. Therefore, proposing a completely distributed electricity system is counterintuitive to the prevailing policy. However, some of the interviewees still see the advantages provided by DC voltage systems as being a strong argument for distributed generation. As interviewee 18 stated “*If you are auto consuming and not connected to the grid, then you would not be paying any grid charges, which obviously take up about 20% of the bill so there are advantages to doing this.*” Counter to this is, if the homeowner was able to claim a feed-in tariff (FIT) this will now be lost, however given that cutbacks in the FITs by the Government (in 2015) this loss may not be as significant as in previous years.

‘If it isn’t broken don’t fix it’ is a maxim that encapsulates people’s locked-in attitude. In interview 12 the concept of the vulnerability of the national grid to cyber or terrorist attack came up. The incident in the 1970s where alleged IRA terrorists planned to destroy the grid supplying London (Nye, 2013), was used as a reason to show the vulnerability of the centralised system. Interviewee 12 stated that ‘*I don’t think that you can say the national grid type system is actually that vulnerable, actually historically it has worked very well that is why there is not the kind of big political drive*’. **The question for 21<sup>st</sup> century energy policy is, does it have to take into consideration possible weaknesses in the electricity system, or**

**should energy policy only react to external landscape pressures once they are in existence, i.e. should energy policy be proactive or reactive?**

For those interviewees who saw the office as being the more appropriate place for DC voltage, there was still concern that there would not be enough energy generated to meet all the needs of a modern large office environment. As interviewee 10 put it “...*but there are substantial holes in this argument related to power supply. How do you generate enough energy for the office for example, how do you supply it? How do you balance supply and demand each second, so that productivity is not lost?*” Therefore, they stated that there would always be a need for a centralised system. Similarly, given that the UK has one of the most inefficient housing stocks in Europe (Guertler et al., 2015) there were concerns about how such houses would meet peak winter loads, (particularly for heating) if they were off grid (interviewees 12 and 18)

The idea to use DC voltage was new to most of the interviewees. Therefore, even those in favour of rooftop solar, saw PV systems in the context of an AC consumption system. In fact, none of the trade associations and business promoting the use of solar generation, including Tesla and Moixa, while promoting DC generation with storage still don't see DC voltage replacing AC in the home.

**Therefore, about decentralising the UK electrical system, “*I think it is good to champion it, we need more narrative, more conversation and more evidence about how that would work*”** (Interviewee 11).

### **5.6.2. AC verses DC systems**

Note: this part of the discussion is the opinion of the engineers and therefore focuses mostly on technical issues. As stated, the most fundamental question about this research is if there exists a fully functioning AC electrical system why would one want to have DC systems? A prerequisite to this discussion is to understand that DC technology, for a fully functioning DC voltage house, does not yet exist. Therefore, all the interviewees who discussed their opinions about AC verses DC were from the viewpoint of the centralised AC system. In their discussions they were trying to highlight either barriers or enablers to DC from within their

AC mind frame, therefore many of their opinions have to be taken as a snapshot as is in 2015. In the future as the AC and DC technology changes, so will opinions.

The first question to answer when deciding on AC or DC is: what are the *efficiencies* of the components within the electricity system and therefore the losses? All engineers know that AC technology loses electrical energy through heat. The question is, is this inherent to AC and can, or are there, new technological steps being taken to reduce these losses. From Calwell (2002) a cheaply made AC transformer could lose more energy in transformation than is absorbed into the battery on charge, i.e. for every 100 Watts of energy inputted into the transformer it was delivering 45 Watts to the battery. However, interviewee 10 stated that using the latest ‘Switch Mode’ power supplies it is possible to have a 96-97% efficient transformation and that *“definitely in 2015 a good quality switch mode power supply is as efficient as an AC to DC transformer”*. Interviewee 20 stated that with technological advances in AC design, the marginal difference between AC and DC is small enough to negate any thoughts of a DC ring main in the home. Interviewee 19 maintained that: one, many of these AC transformers are still manufactured with a minimum specification and two, these efficiency values like 99% are only valid at full load. However, the inverter, for example, in rooftop PV systems will rarely be operating at full capacity, as solar is an intermittent energy source therefore the actual operating efficiency will be much lower than the quoted 99%. As interviewee 19 said:

*“What I do know is that inverters and switch mode power supplies are being used on solar panels, the cheapest ones passed the standards at full output in terms of waveform quality, but at part load where most of them operate at most of the time, they have horrible wave forms and the better design, which keeps its waveform quality across the range is more expensive and isn’t adopted.”*

Rooftop PV systems always need a ‘maximum point power tracker’ regardless of whether the system is AC or DC. Interviewee 5, who is an engineer, pointed out that since some sort of DC to DC conversion and battery management systems will be needed, there is only a marginal cost difference between the DC and AC technology that in his opinion makes staying with AC for transmission within the home more sensible. This same point was brought out by other interviewees who saw the need for DC to DC transformation and therefore introducing a new set of losses similar to the AC to DC transformation: as

interviewee 6 stated “...if you’re not careful you are swapping one set of inefficiencies with another which doesn’t move the game further forward.”. Interviewee 5 said: “AC to DC power supplies are becoming increasingly efficient. The cost benefit analysis just makes it not worthwhile that is much more likely to kill DC, than a lack of research”. However, DC is being used in the IT environment, that includes the usage of 380 V DC systems by the Met Office, 24 V DC systems at The University of Bath library, the Bristol SoLa project (interviewee 8) and data centres across the world use 48V and 380V DC (EMerge Alliance, 2013). **Therefore, further research is needed to settle this efficiency and energy consumption discussion.**

Interviewees 8 and 9 had installed, in a library and 30 houses, a DC system for IT and lighting and low powered loads. Both these systems were powered off the AC mains and the AC system in the houses was still in use for the higher-powered loads. However, they were able to measure significant advantages with the use of DC voltage even though only part of the overall electricity supply was DC. Computers are electronic and therefore require DC voltage to operate. Each has a universal power supply (UPS) that internally converts the AC voltage to the different DC voltages required by different parts of the computer. The characteristics of AC electricity are that its voltage output is sinusoidal in form and is at a frequency of 50 Hertz. There is a phenomenon called ‘harmonic distortion’. This is similar to water waves that hit the wall and bounce back, some cancel each other out while some combine to create larger waves. Similarly, in AC systems the electric ‘waves’ create harmonic distortion that is injected back into the electricity supply and reduce the power factor of the circuit: “...total harmonic distortion is excessive on the AC network” (Interviewee 9). To stop these distorted ‘waves’ destroying the electricity circuits, large filters are used to block them. As well as this, sometimes to lessen the problem, the size of the input AC system (wiring etc.) is made bigger to counter the harmonic distortion. Both these problems add costs to the customer. However, what they found when they converted the library computers to operate with the DC voltage supply was, that the 3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup> harmonics were much reduced. This therefore saved both energy and money on a large input filter.

As stated, AC power supplies generate heat. Therefore, when they were removed from the library computers, they found that there was less usage of the air-conditioning system

throughout the year. Even though on cold winter days they had to turn the heating up, both interviewees reported that overall energy consumption went down. Another advantage of the DC system was that the noise generated by the fans within the UPSs was eliminated, this made the IT environment quieter and therefore more attractive to the students. The IT environment was on a time-of-day tariff, which means that the charge per unit of electricity is higher at peak times of the day and lower in off-peak times. This system used battery backup to provide security of supply in times of power cuts and to offset its use of electricity from peak to off peak times. By charging the battery bank in off-peak times and using the stored electricity at peak times they were able to save the difference in the on and off peak tariff. This is known as load shifting (Caves et al., 1989). In both the IT project and the houses, it was reported that the overall electricity bill went down. The cost benefit analysis, including the payback period for the DC system is not known. Interviewee 15 discussed the advantages and disadvantages to using AC or DC motors. In his final analysis he stated it would depend on the design and size of motor used, sometimes it is better to use AC and sometimes DC. **Therefore, there is a need to undertake more research in comparing AC and DC systems.**

Given that the interviewees see things through the eyes of the present AC system, none of the interviewees could envision a UK without the national grid system and AC voltage. Where they saw DC was as local generation with all its advantages and for only powering very low powered appliances and LED lights. They saw a house with both AC and DC ring mains, each with a different type of plug, as existed within the UK and France up to the 1980s. The AC would be for devices that required more than 1KW. Interviewee 6 compared this to the USA system that supplies each property with a 2 or 3-phase supply and appliances have either a two pronged or three-pronged plug depending on the voltage required. These were part of the scenario analysis for the DC house highlighted in previous research (Kinn, 2011a, Chapter 5). **Therefore, there is the need to do innovative research that will form the foundation for the use of DC voltage for more than 1 kW loads.**

### 5.6.3. The role of the utility company

One of the discussions around the usage of distributed DC is how will this affect the utilities and what will be their role in the future? The UK electrical system is broken up into different regional and market sectors each one feeding into the other. However, there are some of the large companies that are vertically integrated, *“so they are both the generation owners and the retailers, now those are separate arms and have Chinese wall ring fenced organisations”* (interviewee 19). Nevertheless, as a company they control the whole vertical process from generation to selling to customers. Within this discussion PV or wind were looked at from the point of their intermittence and how that affects the national grid, i.e. how will it fit into the incumbent centralised system. There were those who saw the large national utilities becoming defunct or changing their whole business model, while others who could only envision a centralised system saw the status quo remaining.

Many of the interviewees saw the utilities as being a strong barrier to DC proliferation. It was explained that through their ‘marketing’ and lobbying efforts they convince the policy makers to not only keep the status quo, but also to introduce mechanisms into the market that help them keep their hold on the market. As interviewee 6 put it *“Basically energy companies are rewarded for selling people more electricity, therefore it is not in their interests to reduce consumption”*. Others saw the utilities shrinking as centralised generators of electricity and moving to the ‘energy service company’ model as rooftop PV proliferates. The new types of services utilities could provide include: data management, selling a level of ‘thermal comfort’, owning the hardware, as in ‘rent-a-roof’ schemes and providing health care and elderly care services and consultative advice. It was pointed out that one must look to Germany to see how the national utility companies are transitioning their business models.

According to interviewee 18, the European and American utilities have had their credit ratings reduced in recent years (2015) as they are seen to be vulnerable to a trend towards distributed generation.

*“I think the existing utility business model is going to become defunct quite quickly, you can already see that the credit rating of the European-based utilities companies have already been massively slashed, the entire US utility sector credit rating has been slashed quite recently...”*



Richter (2013) has warned that if the German utilities do not invest in customer-side renewables they will continue to lose market share. Furthermore, he found that: *“A surprising result is that most utility managers do not see renewable energy as a threat to their current business model, although utilities have already lost significant market share to investors from outside the industry.”* This mind frame is definitely a barrier to be overcome, if the utilities are going to play any part in DC proliferation.

#### **5.6.4. Energy security and energy independence**

Besides the discussion on the technical issues relating to AC and DC, there are the ramifications that a distributed DC electricity system may have on society. The concept of energy security and energy independence has been discussed in Chapter 1 and within the literature review in Chapter 2. Through the interviews, it was hoped to get an understanding about what people understand by these concepts, to see if they are a single interlocking concept or two separate concepts and to see how these views may affect the transition to DC.

For those in the developing world that are not connected to the electric grid, there is the anxiety about having adequate energy supplies, whether in the form of batteries or having an adequate supply of fossil fuel. In the 1980s, ‘wind up’ technology stepped into this arena. *“This idea of a wind up radio meant that you never have to buy batteries again, captured the public imagination.”* (Interviewee 6). Wind up technology has now been superseded by solar charging, like SolarAid’s solar lamps in Africa (SolarAid, 2016; World Bank, 2011). Similarly, today with regard to the take up of both electric and hybrid hydrogen cars ‘range anxiety’ deters many from buying such cars. What drivers are worried about is running out of electric charge far away from a re-charging point. To counter this, a program to create a network of charging stations and hydrogen filling stations has now (in 2015) gained momentum.

The worry about running out of energy is the essence of what many understand to be the meaning of ‘energy security’, which is synonymous with ‘security of supply’ as used in the electricity generation community. Most interviewees understood ‘energy security’ in this way and did not immediately associate energy security with energy independence. The prevailing thoughts were that as long as the availability of primary fuels for the UK’s energy

system are secure, then the UK has energy security: as interviewee 12 put it “*Well, first of all I think those are two different things. You don’t necessarily have to be independent to be secure and a case like Germany shows you that immediately. Germany has practically no indigenous energy resources, but it has had a very secure energy system since the Second World War*”. As he put it, energy security is about having in place ‘*long term contracts for supply*’ and in the short-term ‘*system security*’, which is about being able to have within a half hour or second by second timeframe both ‘*energy and power balance*’

Interviewees did not associate Chinese or Russian geopolitics as a concern for the UK’s energy security. Furthermore, many of the interviewees gave little importance to the goal of energy independence for the UK, as it seemed to them to be presently unattainable and therefore of little immediate importance to energy policy. When asked if energy independence and energy security are a single goal to work towards, many were not sure and a few saw these two goals as not interdependent i.e. as two different concepts. Interviewee 12 saw energy independence through the eyes of strategic energy storage, which only gives energy independence for a short time until the stock runs out. He stated the following: “*So you could think of energy independence as having a time dimension as well. So the UK has for instance some gas storage that will last probably about two weeks, if you cut off all gas supplies to the UK, for those two weeks we would be energy independent, but after that we wouldn’t.*” Interviewee 12 further pointed out that the UK government energy policy while increasing its electrical energy security via new undersea links, is in fact increasing the UK’s interdependence with the EU, which was seen as weakening the UK’s energy independence. “*I’m not sure that the government is doing anything to increase the UK’s energy independence. I think that they do not think it a good policy objective. If anything they are doing quite a lot to increase our interdependence with the rest of Europe via undersea cables.*” Interviewee 17 saw this interconnect as an opportunity to take advantage of ‘*...the overcapacity in Europe and that will bring down costs*’, yet another saw it as backup against the intermittence of renewables.

All this discussion must be seen within the context of the prevailing centralised generation system and where the primary fuels are a commodity, supplied via a global market mechanism. However, within the context of this research, the electrical energy to the built

environment is provided by a distributed generation system that employs roof top solar panels and a backup system. This system can therefore be described as having energy security with energy independence. For the discussion about energy security and energy independence see Section 3.5.3.

In summary, the discussion around the transition to distributed DC voltage electricity systems is ongoing and only **through further rigorous technical research will the issues be resolved**. Furthermore, while distributed generation systems are seen as a way to enhance systems reliability it was hard to find any of the interviewees who would be comfortable having their homes completely off-grid. **It is therefore important to ascertain what could be done to imbue users with the confidence to go off-grid.**

## **5.7. Theme 3 - Coalition building – W4**

The importance of *dialogue* in the process of a transition has been highlighted in Section 3.3.8. It is about dissemination of knowledge that may have accumulated in a niche environment into mainstream thinking in the regime level within the MLP. Dialogue exists as interactions between actors within a single institution and between actors of different institutions. Therefore, questions were asked to interviewees to find processes of interactions, dialogues and structuration that would be part of the transition from AC to DC and which people would be the implementers within the transition. The interviewees stated that there is a need to form a coalition of likeminded people, perhaps with subgroups that will deal with individual aspects of the transition, but are coordinating their efforts within an umbrella coalition. But how does one get people to come-on-board and be part of the transition process from within, rather than being onlookers? Then the questions are, who are the people, what calibre of people are they and how did they reach such a level of trust? This is W4, *who*, of the 5Ws. This theme looks at community building, education and knowledge dissemination.

### **5.7.1. Developing a community from a team**

A new project even if one person initialises it, needs a core team working together from the beginning. Interviewee 16 was asked: how would the DC project get off the ground? His reply was “*You have got to do a lot of work and put forward a business case, equally so it is kind of*

*a University exercise, this is something that universities do very well blue sky research*". Therefore, a university based DC research group could be set up to provide arms-length independent rigorous research that would attract research grants, industrial investment and partnership opportunities. Interviewee 19 pointed out that a university will produce methodologies and standards that would be singular to the market and even open standard, examples given were the GSM and USB standards. Whereas, when industrial research develops bespoke and competing standards for products, it may not be good for the market as early adopters may end up with 'stranded assets'. From interviewees 4, 6 and 15 the following examples of competing standards has been drawn: Sony's Betamax and the JVC's VHS standards and Toshiba's HD-DVD and Sony's Blu-ray standards. Another problematic outcome of industrial research could be "*capture by the market*" (interviewee 11) where a sub-optimised technology becomes locked-in as the industry standard (see Section 3.2.7 above). It is interesting to point out what could happen if the DC standards were left entirely to the markets. By the late 1920s in Greater London there was no less than:

*"80 different supply authorities  
50 different systems of supply  
24 different voltages  
10 different frequencies  
70 different power stations"* (Gordon, 1981, p. 29)

Over time what should emerge is a research group that has gained a label as a 'centre of research excellence', with people who become acknowledged experts in the field of DC systems. These experts become 'technology champions' and are the spokespeople for advocating DC voltage. Any cause needs its champions whose opinions are respected and acted upon. The name label given at the Global Sustainability Conference 2015 held at Anglia Ruskin University for such a champion was a "*reputable messenger*". These are the people who are interviewed by the media and have the ear of politicians and industrialists. Some of the interviewees saw the 'reputable messenger' as being the person in their own right, while others saw it as being the position they hold within a 'centre of excellence' as being the 'reputable messenger'. As interviewee 13 put it: "*The vast majority of reputable messengers carry that weight because of the position that they hold rather than them as individuals. It is very rare that you have an individual that is listened to because they are that particular individual*", i.e. because they represent a certain organisation people listen to what they have

to say. As interviewee 17 put it *“Policymakers only listen to people who they trust and it takes a long time to gain that trust.”*

A small team may suffice at the proof of concept stage (interviewee 9’s team consisted of three people) and a larger one at the prototyping and pilot stages (interviewees 1, 8, 9, 10, 11 and interviewees 15 spoke about his *“business leadership team”*). However, as with the development of a standard, getting the project out of the research arena and into the public arena will require the cooperation, skills and knowledge base of many different functions across the whole lifecycle of the project (interviewees 1 & 11). For DC there are already many organisations working within this generalised space: from manufacturers and software developers, to all those involved with the IETs’ CoP for DC, together they must form a coalition of likeminded people who have *“common overarching interest”* (interviewee 1) in the development of DC voltage systems. A good example of this type of coalition building is the Emerge Alliance in the USA (interviewee 1) who are working on 380 V DC systems for the office. The disadvantage of this type of industry-led coalition is that its ultimate goal is commercial, which could lead to *“capture by the market”* (interviewee 11). As interviewee 4 put it:

*“I think that one of the benefits of engaging with a professional body is the ethics that the professional body bring to the party, so if you created an engine that could run on water and you took it to a trade association and said I have this engine that runs on water they would bury you and your engine as far away as possible as it is going to impact on their profits. If you take to a professional body because a professional body is about the enhancement and benefit to the public they should embrace that and not be constrained by commercial interests”.*

Therefore, independent research establishments, some of which are listed below, should be prominent in any coalition.

Some of the people and organisations suggested by interviewees to be incorporated into the coalition are:

- Government: DECC, BIS, POST, Home Office committees, select committees
- Professional organisations such as the IET, RICS

- Trade organisations such as, The Electrical Contractors Association, the Solar Trade Association, British Electrotechnical and Allied Manufacturers' Association, Building and Engineering Services Association, Association for Decentralised Energy
- Independent national bodies such as: The Building Research Establishment, the Construction Industry Research and Information Association, Federation of Environmental Technologies Association, Building Industry Research Association
- Academics and research groups such as: Dita Helm, Jim Ski, Jim Watson, Catherine Mitchel, Paul Eking, Strathclyde university, UCL, Imperial Collage London
- Think tanks, e.g. Policy Exchange, IPPR
- NGOs such as Green Peace, Friends of the Earth
- Corporate investors
- Distribution network operators, e.g. Western Power Distribution
- Systems Manufacturers such as, Siemens, Schneider, Terasaki
- Professionals working on mass storage, the Energy Storage Network
- Appliance manufacturers
- Start-up tech companies
- Installers of renewable energy systems
- People working on DC systems for ships and satellites
- Electrical component manufacturers
- Architects, house builders and researchers in the built environment
- The general public, i.e. The users

Such a coalition should be guided by what some called a 'steering committee' that comprises the lead individuals leading the project. This is akin to 'business leadership teams' within organisations that bring together all the elements needed for a success. So what are the mechanisms used to bring people together? Coalition building is best done face to face in what interviewees 1 and 2 called 'scoping'. This is when an idea is presented to the 'public', through special events like workshops, special one-day conferences, round table discussions, organised to bring together likeminded people with a goal that some of them will join the coalition. Further discussion can be on-line, in the media and through publishing reports and articles in professional magazines, trade journals and through conferences.

## **5.8. Theme 4 – Developing a niche technology - H1**

Geels (2011) explains four pathways a niche technology can take in order to break into the regime and become the dominant technology (see Section 3.2.5). However, his paper does not give the details about the processes through which the niche technology goes in order to achieve dominance. Therefore, what are the individual steps within the transition pathway, for DC systems to become dominant in an AC world? This is the first stage of the ‘*how*’ will the transformation to DC systems be able to take place. The theory suggests that it must first succeed within the niche before it is able to break into the regime. This theme will discuss the stages a new technology has to go through within the niche environment to complete the prototyping stage of product development. However, at this stage there is one question: should a DC prototype system aim to provide a solution for the commercial building/office, or for the home?

Many of the interviewees (1, 2, 4, 5, 6, 7, 14, 18 and 19) were chosen as they had extensive knowledge and expertise in funding and financing a project, in ways of developing a new idea and in methodologies for successful implementation. The information gathered from them was more generic and less to do with the specifics of a transition to decentralised DC voltage systems. What they provided was the many generic steps needed for a new niche concept to successfully transition. In the US-based Product Development and Management Association’s Handbook of New Product Development, the product development process is defined as “*A disciplined and defined set of tasks, steps and phases that describe the normal means by which a company repetitively converts embryonic ideas into saleable products or services.*” (Kahn et al., 2005 (eds)). Much of what is written here is from interviewee 6, who explained in great detail the three stages of product development, an invention has to go through to succeed in the marketplace. He explained this as he saw the transition to DC electricity as being similar to the process for an invention.

The initial goal for any invention is the production of a prototype. However, to reach this stage the inventor needs to: (1) find funding, (2) have the ability to do research and (3) understand the fundamental components for success.

The conceptual stages of the DC project have already started within a university environment that is this research. Further work is highlighted within this research. After this the next stage will be proof of concept leading to the production of a prototype DC house. This stage may be a single stage, or may be split between research into the appliances and building a working prototype DC voltage home. The fundamental concepts that the house must show are: what energy efficiencies, economic, environmental and social benefits can be gained with the use of DC within the built environment. These concepts are the global concepts that align DC systems with the Global Energy Challenges in Chapter 1 above. Furthermore, it must show what the benefits will be to the ‘markets’ otherwise DC is a “...*solution looking for a problem*” (Interviewee 6). Showing this evidence-based proof will be catalytic for a successful transition.

#### **5.8.1. Funding mechanisms across a whole project**

One of the social networks is the ‘finance network’, which provides the funds needed for a transition. The funding mechanisms available for the DC project formed an important section of the interview questions. From the interviews it was apparent that to fund the proliferation of DC voltage systems, a three-stage approach will be needed, akin to the stages of funding for consumer goods. Firstly, it is important to understand what funding is available, i.e. where does one go to find funds? Secondly, it is important to understand the methodologies needed to be successful in procuring funding and finally, who to partner with to stop the project floundering due to lack of cash flow. The discussion about funding has been placed within this theme, even though it is fundamental to the ‘how’ of all stages of the project, in order not to fragment the subject across many themes.

In general, there are three possible funding routes, the first is public funds that come from the main Research Councils and through government departments (like DECC and BIS) and organisations like Ofgem, Innovate UK, the Catapults etc. The second stream of funding comes from what is called ‘foundation’ funding. These are grants from private philanthropic organisations, like charities and foundations, for example the Dyson Foundation. In addition, the third stream of funding comes from private sources, from what can be called the ‘market’ and includes, universities, business and the capital markets. Many of these funding routes



have specific criteria and provide funding at specific stages of project development, while some offer funding throughout the project development cycle. Many of the interviewees were knowledgeable about funding routes, while interviewees 2 and 7 were experts, one worked for RCUK and the other worked for EPSRC. Much of the university based funding is what is called ‘matched funding’ whereby the university may typically provide 20% and a Research Council 80% and may also include business as the third partner.

There are seven Research Councils, each specific to a research sector. To receive Research Council funding, researchers must be able to show that their research besides fulfilling a specific need is also in alignment with the Council’s delivery plan (interviewee 2). There are two ways of applying for such funds; one is to answer what is known as a ‘**call**’. This is when a Research Council will ask for applications for funding for a specific concept, “*This is competitive funding so it is reasonably hard to get*” (interviewee 5). The second way is ‘**responsive mode**’ funding, this is when an academic approaches a Research Council any time of the year with a proposal for funding that is not connected to a ‘call’. Research Council funding can be in the millions of pounds, which is why it is usually sought after the conceptual stage of research has been completed. To be successful a research proposal has to include the following: (1) show that the project is in alignment with the delivery plan of the funding institution, (2) provide impact indicators that show national, economic, social and environmental importance of the research and (3) be able to withstand peer review. The greater the national importance and the higher the impact, the greater the possibility of having a successful bid.

Ofgem funding comes in two guises, The Network Innovation Competition (NIC) and the Network Innovation Allowance (NIA). Both of these are through the electricity network companies called ‘distribution network operators’ (DNOs), that act as business partners with academia, to develop new technological solutions that “*Should be realising value back to the customers.*” (interviewee 18). The NIC funding is a £100 million pot that the DNOs bid for in order to undertake large new innovation projects and the NIA funding is for early stage funding and is for much smaller amounts. This is not actual Ofgem money, it is a scheme managed by Ofgem, with the funds being added to customers’ bills by the DNOs.

Interviewees 3, 8 and 9 actually worked on DC projects and they indicated that it was an uphill struggle to get the initial seed funding from within their organisations. Interviewee 3 indicated that ‘finance’ was a bottleneck to his DC project. One has to be able to convince the finance department within the organisation before anyone else can be convinced. As interviewee 16 put it *“If you don’t persuade the bean counters to give you any money you’re in trouble.”* Interviewee 5 and 9 indicated that they went through stages of funding, starting with EPSRC and then getting NIA or NIC funding in collaboration with a network operator.

Interviewee 7 stated with regard to transitioning to DC as follows:

*“If it was seen to be a big multilateral cross council, multi-disciplinary or interdisciplinary research theme, for changing the electrical system in the UK, you might be thinking, well you have the underpinning research that will need to be done on the electrical systems, you then probably also got research into behaviour, how do you get behaviour change. How do you make this transition, you also most probably have got a bit of policy work to be done, sort of government policy wise what would you need to change and you might also want some business studies research in there. How you would get industry to come on board and what lessons can you learn from other changes of systems. So if it was straight, like just looking at the underpinning science, which fits into this area then we would refer you to the individual research councils that would deal with that. If it was across a couple of Research Councils, we have what is called a cross council funding agreement which makes sure that no multi or interdisciplinary research gets lost in the gaps. If it was actually a much bigger research theme that would draw in several of the research councils, then it would be something that the Research Group would look at and look at how that can best be developed across the Research Councils. So that would be when our organisation and its systems would come into play.”*

Therefore, the DC project that looks into the transitioning of the UK’s electricity system to a decentralised DC voltage system is a ‘cross disciplinary market transformation project’. As it is sociotechnical in nature it will sit across both the Engineering and Physical Sciences Research Council and the Economic and Social Research Council and may also include the Science and Technology Facilities Council. The DC project is therefore a multi-disciplinary and cross Council research project. It has therefore been suggested by interviewee 7 that for funding the DC project, a responsive mode bid should be made to the EPSRC and within the proposal it must be highlighted that this is an interdisciplinary research project and as such to request within the proposal that RUCK get involved to create a ‘cross council funding agreement’. Such a proposal will have to be placed via a university and it was suggested by

interviewee 12 that this could be done within the context of an Early Career Fellowship. It was also suggested by interviewee 2 that such a funding bid would have to demonstrate that it is aligned with the EPSRC's Capability Program themes of 'engineering' and perhaps 'physical science' and the Challenge Program themes which look at global grand challenges of 'energy' and 'living with environmental change'.

It was suggested that besides the Research Council funding which could be for the initial stages of the development of a DC project, there is also Innovate UK (interviewees 10, 18 and 19) and the Low Carbon Network Fund (interviewees 9 and 12). Interviewee 19 further suggested that, *"if you could show that there was some significant advantage for DC and if there was then you might get to a stage where Ofgem's innovation funding and working with a willing DNO could be used to build a housing estate of DC homes or something."* This could be like the SoLar Bristol Project. However, these demonstration houses will be fully DC and off-grid houses. This would be the end of the second stage 'prototyping' needed to demonstrate the advantages of using DC voltage electricity.

After the interviews were conducted, the Nurse Report (2015) came out. Depending on how the future structure of the Research Councils develops, the process for interdisciplinary research funding may change.

### **5.8.2. Prototyping - Technology Alignment**

Besides aligning the goals of a project with the goals of a funding body there is also the alignment of the technology with the 'market'. Inventors have ideas yet many of these ideas either never make it to market, or when they do, fail to sell in enough quantities to be viable and quickly disappear from the market. This does not mean that it was not necessarily a good invention, but that the inventor missed fundamental concepts for a success. Interviewee 6, whose expertise is in helping new inventors, said that only about 5% of ideas that he sees are likely to succeed. Making something that people need and marketing it in such a way that people will buy it, is fundamental to success. This ability to align the invention with the market must start at the seed funding stage and is equally crucial for a successful transition to DC systems proliferation. According to Van Kleef et.al (2005, Abstract) *"Incorporating the 'voice of the consumer' in early stages of the new product development process has been*

*identified as a critical success factor for new product development. Yet, this step is often ignored or poorly executed.”*

Interviewee 14 was the only interviewee to connect the transition to DC to being a market transformation activity and as the interview went along changed the transformation from simply “*a market transformation*” to “*a major market transformation*”. He further stated that the transition to DC perhaps will have to be aligned with the UK’s “*market transformation programme*” for sustainable products which was run by DEFRA. Introducing a new technology or innovation into the market, which over time penetrates a large portion of the eligible market, is a market transformation activity (Geller and Nadel, 1994). Examples of market transformations they give are: compact florescent light bulbs, the computer and gas filled double/triple glassed windows. Therefore, the introduction of DC systems into the built environment, whether it is in a country that already has a national grid or a country that has part of its population not connected to the grid at all, can be considered a market transformation activity.

According to Interviewee 6, understanding the 3-stage approach to prototyping of consumer goods helps in the understanding of the transition to DC electricity systems. However, initially an inventor must ask the question, what problem, function or need is my invention trying to deal with? The first stage of prototyping is proof of concept: “*...proving the fundamental method or functionality of the device.*” by building a basic model to do some fundamental measurements on the usability of the device. The second stage is “*kind of proof of technique*” or what Interviewee 6 called “*engineerability*”: which are refinements that deal with the practical issues that will allow the machine to work. The third stage is “*readiness for market*” or prototyping the product: which is about being able to manufacture it in a way that is sellable at a price that people will buy it. This stage is about selection of materials and manufacturing process. Marketing is a specialist skill and it is needed throughout the “*readiness for market*” stage and as a tool to generate consumer demand for the product.

Some of the interviewees (3, 5 and 6), saw the proliferation of DC, first in the office environment and then in the home. This is based on the fact that the office is now a focus for technological innovation (EMergeAlliance, 2015; Fregosi et al., 2015; Weiss et al., 2015; Wunder et al., 2015) for data, IT and lighting systems. Interviewee 20 said “*Have a look*

*under the Hub Net project. There is a stream of work at Imperial, which is looking at a low voltage DC desk for commercial premises.”* It was stated by interviewee 5 that the home will be slower to adapt because office refurbishment is once every five or six years while the home is once every fifteen to thirty years. Interviewee 19 pointed out that the Tesla ‘Power Wall’ battery system, the ‘Power Vault’ systems and the Moixa ‘Maslow’ battery system all now provide a technological solution to home electricity storage, but due to their expense, the domestic uptake will be slow until their price falls. Also, new to the market in October 2015 is the ‘MyReserve storage battery’ from Solarwatt GmbH (see Section 2.2.5). While storage can be used to provide accumulated power from batteries to power larger domestic loads, it has been shown by the Project SoLa Bristol that in 2013 storage doubled the cost of their system (Duan and Redfern, 2014). However, with more technological developments and mass production, as the home battery market matures the cost will come down. Cheaper batteries will help in the proliferation of domestic DC voltage systems. **Therefore, the jury is out as to whether in the future the development of a full prototype DC system will be first for the home or the office, but for a prototype to develop more research and development is needed.**

### **5.8.3. Prototyping a house - important considerations from the interviews**

(1) Electricity connection: In the 1930s, before parts of rural America were on the national grid, there were washing machines that were driven by 2-stroke engines using ‘farm fuel’. These washing machines were belt driven from an external electric motor (interviewee 16). It was pointed out by interviewee 15 if the electricity transformation system, now built into all home appliances, could be separated from the appliance and embedded into the wall socket, this would make the appliance less complicated and cheaper. This could inevitably introduce multiple plugs, one for each voltage required or as with the ‘green plug’ (2015) the electronics via a ‘hand-shake’ as used now in the USB and Ethernet standards, could be used to provide the correct voltage levels. Such technology is what is called smart appliances and the internet of things (Lu and Neng, 2010), which in 2016 are still in their infancy and has been discussed by Kinn (2011b). Smart technology combining data management is seen as a way forward to demand side management (Goulden et al., 2014; Strbac, 2008).

(2) Data Centres: Data centres, that employ a huge amount of electronic technology, have for many years used DC voltage to run their systems and employed battery backup in case of electricity outages. The advantage of this is that they are able to remove all the AC to DC converters from the computers. This reduces the capital outlay for the hardware, it reduces heat generation in the electricity transformations and therefore the amount of air conditioning needed and as there are fewer parts to the system, the mean time to failure is longer. Interviewees 1 and 3 saw data centre technology as a catalyst for office and then domestic usage of DC voltage. Currently the argument and advantages for using DC voltage within data centres is well understood (Pratt et al., 2007; Salomonsson et al., 2007; Simanjorang et al., 2011; Ton et al., 2008), whereas for domestic usage the discussion is still not prominent and is counterbalanced in the UK by the inertia to keep the status quo for AC voltage.

(3) Brick storage heaters: There are still between two and three million night storage heaters in the UK. Interviewee 10 pointed out that night storage heaters could be used as a means to store solar energy during the day using PVs and used at night to heat the house. As these already exist there should be no modification needed to be done to them as it makes no difference to them if they receive mains electricity or electricity from PVs. Also as a low tech solution compared to a high tech rare-earths battery they will be much cheaper. **However, if they need any modifications to operate with DC voltage electricity is not known and could be for further work.**

## 5.9. Theme 5 - Second stage project development - H2

The production of a prototype completes the ‘proof of concept’ stage, which is the first step in bringing a concept to market. The second stage is about expanding the project to develop a pilot project that operates outside the research arena and engages with the public. This is the stage of preparing it to successfully emerge from the niche into the sociotechnical regime. The goal of this second stage prototype is ‘*Where you need to interact with real humans and families, perhaps half a dozen houses on a new housing estate*’ (Interviewee 19). At this stage many of the activities that happened at the proof of concept stage are not just scaled up, but there is now the opportunity to bring many new processes on-line. These include: higher levels of funding, standards, greater engagement with policy makers and developing the

mechanisms for a successful proliferation into the market. How these individual processes are transitioned, is the second stage of the '*how*' of the transition to DC systems.

This theme deals with standards and policy making that are two of the social networks that came out of the literature in Chapter 3 and adds some aspects of institutional structuration.

### **5.9.1. Standards**

That standards are needed for a transition to DC was known before undertaking the interviews, but to what extent and which type was something that came out of the interviews. Only interviewees 4, 14 and 16 had extensive experience and knowledge about standards, therefore much that is written here is paraphrased from their interviews. Some had basic knowledge while others, especially the non-engineers, knew almost nothing about the state of existing standards or if any new ones would be needed for the proliferation of DC voltage systems. It is therefore important to understand the processes and difference between the different types of 'standards'. Here the word is used very loosely and includes: Codes of Practice, Regulations, Industrial Standards and standards that are policy instruments underpinning government policy. Given that transitioning to distributed DC is a market transformation transition, all these levels of standards will have to be produced as part of the transitioning process.

Many standards are initiated via the EU or governments and are there to support policy. These are the highest level of standard and usually provide the framework to inform the market about the parameters of the policy, for example the Building Energy Performance Directive (European Union, 2003) or the Marketing of Construction Products Directive (European Union, 2011) (which was driven by a free trade policy). These can be driven by the European Committee for Standardization - CEN, the British Standards Institute - BSI and the International Organization for Standardization – ISO. These are very widely focused organisations that operate via committees that are made up of representatives from across the whole lifecycle of a product or process. As such, the industrial sector has representation on these committees and not only helps to formulate policy, but are also forewarned so that they have enough time to develop the necessary mechanisms to comply with these top-level standards and to be able to produce methodologies that can create the lower level standards.

From the top-level standards, the market is expected to develop the details. For example, the type of technology needed to fulfil the policy that the standard is underpinning and the methodologies and equipment to safely implement and test the systems developed. Each one of these components will need its own lower level standard. The lower level standard is usually initiated by industry leaders through industrial and professional associations. This lower level standard may not be borne out of a policy instrument, but could be initiated by industrial need to consolidate a market, provide uniformity of quality and stability for future innovation, or like Betamax and VHS it could be initiated by a single industrial player who takes with it a big enough market following to win over its rivals. For the DC project it will be the innovators and their allies who develop the lower level standards. However, interviewee 14 explained that as “*The government are one of the biggest procurers they have the ability to set the level of their own procurement*”, i.e. they are able to drive the market to a certain standard.

At this stage within the UK the IET have already ratified a CoP for DC (see Section 2.2.4). This was done in partnership with industry and academia. The reason given by interviewee 4 for why the UK chose to ratify a CoP rather than a BSI for DC was because, “*...it is an easier process to take that from a code of practice into an established British or International standard but the process going direct to a British or international standard, that drafting process, we just felt would leave us trailing somewhat behind our international competitors.*”. However, in the future this CoP should ultimately become the de-facto standard. Although, within the UK’s wiring regulations there can be found references for DC usage, interviewee 4 commented, “*They fall some way short of the levels of advice that practitioners require*”.

The development of these lower level standards is “*an essential part of the research and development process*” for the development of DC voltage systems and it gives manufacturers “*the opportunity to have confidence to invest in the market*” (interviewee 4). All the interviewees who have technical know-how agreed that at this time (2015) there is no comprehensive set of regulations and standards to govern the use of distributed DC voltage systems for consumption purposes. Although they saw standards as a barrier to the proliferation of DC this is also an enabler, i.e. by producing such standards it will help with the proliferation of DC.



Below are some of the standards that the interviewees would like to see ratified:

- A full standard to a DC ring main within the built environment including a set of DC voltage ratings
- A new Plug and Socket Act
- A more comprehensive safety standard for DC voltage systems
- Updating of the building regulations to standardise the use of USB and Ethernet sockets
- Standardise energy management within the domestic environment to take full advantage of the controllability that DC voltage enables
- A standard that will promote the usage of storage heaters as a means to use off peak electricity.
- A standard that will include the usage of larger currents for domestic usage
- A more comprehensive standard for rooftop PV systems including standardisation of communications and control subsystems and for the quality of the wave-form out of the inverters (not needed for the DC only system)
- A standard for installation and testing of DC voltage systems
- DC appliances will need new performance and safety standards
- A standard or regulation for local distribution of rooftop generated electricity
- A standard that would allow for the development of rooftop renewables by third parties, i.e. energy service companies

One important question about the proliferation of DC is the pathway to its development. Who will be driving these new DC standards, the government, the markets, research or professional bodies? i.e. what will be the governance structure for the DC project? According to Geels (2014b, p. 34) “*The presumed failure of ‘picking winners’ in the 1970s and 1980s led to a preference for the market to decide about innovations, including low-carbon options*” and not governments. This implies the policy makers would rather that market mechanisms lead to the proliferation of DC than it being policy led.

Besides the point raised before about competing standards, interviewee 6 discussed the development of the GSM standard as a reason for DC standards to be produced before there is a DC market:

*“GSM was developed as a standard, almost independent of the development of the technology and the American attitude to GSM was we don’t do that we let the market develop standards and they have regretted it ever since, because they lost the five-year lead in mobile phone technology. The rest of the world said okay, GSM it is, warts and all, we are going to make phones for the GSM standard and within a few years you had phone companies the size of Nokia who got very big very quickly. Motorola who saw themselves as one of the leading component manufacturers for mobile phones, decided not to take up the standard but pursued their own developments and have now disappeared without trace, that was a clear example where **a standard drove the market.**”*

Another example where a standard led the market was said to have been the USB standard. Therefore, the same is concluded about DC: given that this research postulates that DC, besides being a market transformation program, has the potential to be of national importance with regards to energy security and energy independence and that if it is left to the market the potential for competing standards to emerge is very likely, **DC standards should be developed via comprehensive research to drive the market.** Such standards that come before the market are ‘open standards’ which everyone can manufacture to, thus reducing or removing the potential for competing or incompatible technology. As interviewee 6 pointed out, a consumer needs to know that the DC system will allow any appliance bought in the high street to just be plugged in without any problems.

There were varying opinions about the USB and Ethernet standard. Interviewees 5 and 6 were passionate about USB and Interviewee 10 about Ethernet, to become mainstream within the built environment, thus allowing both data and extra-low power to be delivered directly to devices. They say this will be the catalyst for the proliferation of DC voltage in the home, as interviewee 5 put it:

*“It can take 5 W from a USB port at the moment and extends it to be multiple voltages up to 30 V and up to a hundred Watts, you suddenly have a standard socket which is completely internationalised able to power your TV your laptop, your game station, your phone, your burglar alarm etc. and if that really takes off as the USB consortium hope it will that will have dramatic effect on the ability to provide DC power to lots of DC devices in the home.”*

While others were against, saying that these two standards lose more energy than ordinary copper wires. Also, that by removing the power supply out of the device and embedding it to

the wall you cannot always be sure what voltage is delivered to the device, which may result in the device blowing up. As interviewee 16 stated:

*“At the moment people do it, but it is pretty difficult to be sure what that USB output will give, so if you have a piece of equipment you invariably still have to supply it by a power supply. I know they are trying to get away from that with telephones. There needs to be some pretty good standards for the power supply, so that we as appliance manufacturers know that when we plug our device in it will work. Mains voltage is simple, it is 240 volts, 60 Hz full stop and we can design around that. USB can be good, if you design the kit yourself. But there is so much rubbish from China, if you allow the situation you could very well blow up your equipment, you don’t want to do that, you as a manufacturer will be liable.”*

Interviewee 20 had never heard of power over Ethernet and said *“But you don’t transmit power over Ethernet you transmit information over Ethernet.”* **Either of these opinions can be verified through further research to bench-test these two systems with DC loads.**

**This research has identified a lack of standards for domestic DC voltage as a gap in the knowledge base** and it seems that the engineers involved in DC for domestic usage either are agnostic as to which voltage to use or used commercially available products at 24V. No interviewee was able to identify any research that was presently looking into establishing a DC extra low voltage standard for domestic electrical systems for supply, transmission and consumption. In fact, while some of the interviewees identified fellow electrical engineers as the main barriers to DC usage in the home, even the practitioners themselves do not envision a fully functioning DC home for all domestic loads. This opposition to domestic DC systems can only be overcome by further research and knowledge dissemination.

### **5.9.2. Policy makers and a pathway for DC proliferation**

Many of the interviewees who were knowledgeable about policy making emphasised that, for DC voltage systems to become part of any energy solution, policy makers must be brought into the debate. They pointed out that the usage of DC systems for consumption purposes is not at this time (2016) on anyone’s agenda, including policy makers and may be seen as *“...so niche and uninteresting”* (interviewee 12). Therefore, the first step should be to promote DC voltage so that it gets on to the energy policy agenda. It was pointed out by some

of the interviewees, that knowledge transfer to politicians and civil servants is slightly different from general knowledge transfer as described above in Section 5.5.1. A number of suggestions were made that included: writing academic papers, writing short policy briefs, creating an online presence by writing blogs and using social media forums, going to conferences and speaking to people face-to-face, lobbying civil servants within the Department of Energy and Climate Change and the department of Business, Innovation and Skills and actively responding to calls for information from Parliamentary Committees. (Note, as of July 2016 DECC and BIS are now BEIS) These suggestions were not consensus opinions some were more contentious than others. For example, many of the academics (interviewees 10, 11, 14 and 16) suggested writing academic papers, while interviewee 13 who works within the policy field explained that politicians:

*“...you probably do not have time to sit down spending six months reviewing the evidence and digging up every obscure article that has been written in an obscure journal in order to find the answer to the problem. So as I said before, it is horses for courses, you make the best use of the information you have in your hand and the timescale that you have got to do it and with the level of resource that you have to throw at it within that timescale”.*

He explained that politicians rely on policy briefs, which are a very different type of document and suggested the following contents for a policy brief about the usage of DC voltage systems:

*“What is the technology now, what are the proposed areas of improvement, how would it be applied in the real world, for which you have to consider the status quo, societal issues, economic issues and of course, policy issues, whether we are talking about regulatory or legislative changes that would be needed as the said technology developed. And then you would try and identify what evidence is relevant to all of those (policy) options, then you summarise that evidence in a neutral and as impartial a way as possibly you can.”*

This should be about four pages long, with bullet points to summarise and some graphics.

He further stated that “a highly referenced journal article or particular meta-analyses, are extremely important” for politicians. One way to approach busy politicians is through their parliamentary ‘researchers’ ‘or research teams’, by providing them with ‘one or two page summaries’. If the idea gains traction with MPs, then the next step is to be part of ‘an all-party parliamentary group’ (interviewee 11) through which the ideas of DC voltage proliferation

can be advanced. At some point if it shows success the government will take it up. Interviewee 14 illustrated this as follows, *“Work carried out by charities like Solar Africa with the solar lamps showed governments that ideas are workable and when governments see that things work they have a tendency to adopt it as their own idea”*.

Interviewees 10 and 12 were very pessimistic about the Conservative Government (as at 2015) taking up the usage of DC voltage systems and saw ‘political will’ as a barrier to DC proliferation. They pointed out the funding cutbacks to DECC and BIS, to the feed-in tariffs for renewables, their policy of ‘free market enterprise’ and like many governments since the 1970s, their aversion to ‘picking winners’, as some of the reasons why it will be very difficult to get the Conservative Government to introduce the needed policy mechanisms to help DC proliferate. However, interviewee 15 who understood the perspective of the ‘market’ especially that of appliance manufacturers, pointed out that government policy is the catalyst, so politicians must be engaged, because without them the DC project will not get anywhere. However, if there is corporate opposition this may not be so easy, as Geels (2014) points out that *“Barley (2010) showed empirically how firms since the 1970s have rapidly expanded the creation of foundations, think tanks, political action committees, government affairs offices, public relation firms and advisory committees to corral governments and shape public opinion”*.

It was pointed out by interviewee 15 that initially all energy reduction initiatives were driven by EU policy, which was followed by the market leaders who strove to beat the standard. (Note; in the future, depending on the deal the UK gets through Brexit negotiations, these UK policies may or may not be initiated by the EU, however, market leaders will always strive to meet a national or international standard.) This began a race within the product leaders to produce premium products that were better than the standard. Over time, the bar was moved up so that every manufacturer was ‘forced’ to buck the trend and produce better products. However, this would not have happened without the initial policy framework, which gave confidence to the manufacturers to invest in capital expenditure. It was pointed out that this process can have a detrimental side-effect: if government policy changes direction rather than progressing along the same pathway, or if it changes too fast so that manufacturers do not have time to benefit from their innovations before the standard changes, this could stifle

innovation. This is particularly so, as it was pointed out that many of the advantages offered by DC systems will be to the users in the way of reduced consumption etc., so there must be strong market stability that allows industry their rewards. Furthermore, when the government removed 'The Code for Sustainable Homes' in March 2015 which many small businesses had invested in and trained their staff to implement and halted onshore wind farms in favour of deep sea farms (Energy and Climate Change Committee, 2016), these changes in policy created uncertainty within industry and impacted on confidence within the market.

Currently the advantages of DC for the manufacturers do not seem to be so great so '*...they would only do that when they're absolutely sure that they see the policy framework coming*' (interviewee 12). There has been a problem that energy policy has changed the goalposts many times over the last ten years, which has created uncertainty within the market. As interviewee 16 put it:

*"The big problem in all industry is that they keep moving the goalposts and shuffling around and uncertainty is the biggest thing that hits industry, so if we know where we are going for the next 10 years, then life gets a bit easier. But we don't, we keep changing things and there are moves to do this and moves to do that and pressure to do this and pressure to do that, so you just sort yourself out on one thing and they want something else."*

Manufacturers would be less willing to invest in innovations, like DC, as they fear uncertainty. Therefore, regardless of the political persuasion of the government, they have to be engaged in the DC voltage discussion and provide the necessary policy frameworks for it to successfully proliferate. As interviewee 16 stated "*Politicians get wound up when they have cupboards full of power supplies from old mobile phones and they are now saying surely there is a better way of doing this*", so perhaps now is the time to promote the advantages of DC voltage systems.

The type of government policy initiatives that the market would like to see for the proliferation of DC voltage systems is the same for many of the niche innovations that have transitioned in the last few decades. Many of these stated by the interviewees were those that have been used for wind energy proliferation, to attract foreign investment into the UK's transport market and the 2015 deal with France and China for the first nuclear power station that will be built in the UK this century. (Note: As of July 2016, the UK's Prime Minister has

put this project on hold until further consultation.) These government initiatives could be of the fiscal type for example: research grants, tax breaks, or tax credits for innovation, tax credits for new capital projects FITs etc. or they could be of the regulatory type, which could support industry standards or put in place regulation that stabilises the market for the long term. Like the feed-in tariffs for renewables, some of the fiscal incentives are there to grow a market sector and are gradually reduced as the market grows. Others, like the building regulations, are reviewed every few years and as long as they are trending in a direction they reinforce the industry.

The UK government uses public consultations usually via Parliamentary Standing Committees to crowd source ideas to be inputted into government policy (see Appendix 3 for examples by this researcher). Many of the policy instruments within the energy industry were formulated closely with industry, for example the Renewable Obligation Certificates and feed-in-tariffs, the carbon trading scheme and a scheme that gives guaranteed income to generators regardless of the market price which is called Contracts for difference (Department of Energy and Climate Change, 2013). One reason for this is that in order to not look like it is picking winners the government “...tries to find the design of incentive mechanisms that doesn’t leave the technical choices with itself” (interviewee 19).

As the DC project is a market transformation project, for it to succeed it will require long term strategic planning. It was suggested that both DECC and BIS would normally be the government departments to approach to initiate such a project. However, the Conservative Government of 2015 has sought to cut its budget deficit by making wide scale cuts to departmental budgets. So that in mid-2015 DECC “...have no one who is really thinking strategically in long-term vision about how to change the system, they just don’t have the staff” (interviewee 12). The same long term strategic thinking is not at ofgem, partly because the sustainability department is not staffed by engineers and partly because in the whole electricity system there is no “...system architect job like that found in other industries” (interviewee 16).

So far, the importance that policy makers place on manufacturing and the confidence of the market has been shown. Also discussed is ways of influencing the policy makers. However, what is the connection of energy policy to electricity consumption?

Over the last 20 years, according to interviewee 11, the UK's main energy policy focus has been on the supply side of the energy equation, with its main focus on "*low carbon growth*" and the "*transition to cleaner energy*", which has been driven by the global pressure to reduce carbon dioxide emissions. There has been a specific focus on the electricity supply system. This is because 32% of the UK's carbon emissions are from electricity production (Geels, 2014b, p. 24) and as interviewee 17 put it, it is "*...electricity is easier to decarbonise than the heat or transport sector*". With regard to electricity consumption very little market transformation policy has been introduced. As interviewee 17 pointed out, "*There is a culture within the government and within the energy policy community of focusing on the energy supply, rather than thinking about how it's actually used.*" However, there has been some demand side policy driven initiatives, like the transition from incandescent light bulbs to compact florescent light bulbs. This has resulted in 100 Watt incandescent bulbs being replaced by 20 Watt compact florescent equivalents. Further to this a policy that was driven via Europe, to reduce the standby energy losses in electronic goods, was adopted by the UK government (Energy Saving Trust, 2007).

Interviewee 15 pointed out the following anomaly:

*"Everything we are doing around energy in appliances, is to try and save one Watt here or two Watts there and then they switch on a 2 kW heater and if you run that for one second or two seconds longer or shorter that makes more difference than more or less than the rest of the heating system consumes".*

What this highlights is how the effort to be seen to be doing something about carbon reduction has been focussed mainly on the appliance manufacturing industry, with initiatives that the interviewee felt placed an unnecessary burden on his industry. Through the Green Deal, the Warm Front initiative and various supplier obligations, the UK government has focused its energy policy on the thermal efficiency within the UK housing stock. However, as interviewee 15 pointed out, "*I think that very little is done at the UK level for improving the electrical efficiencies*". The overall results of these policies, as Geels (2014b, p. 24) points out is, that the overall carbon emissions from electricity generation has not improved between 2000 and 2012. Furthermore the Digest of UK Energy Statistics shows (MacLeay et al., 2014, p. 241) that the average electricity consumption between 2000 and 2012 was 333.89 TWh per year. It went from 330.59 TWh in 2000 to a peak in 2005 of 349.35 TWh and had been



reduced by 2012 to 317.83 TWh. Between 1986 and 2012 the total electricity consumption has gone up from 250.31 TWh to 317.83 TWh, an upward trend that consecutive governments have tried to slow down and to reverse. Therefore, any new technical initiative like the transition to DC must be able to show that it can be aligned to electricity and carbon emissions reductions.

Many of the interviewees discussed different parts of the larger picture of the DC system that will be needed in order for DC proliferation. Each one is a catalyst for one aspect that will help in the proliferation of distributed DC systems.

(1) Licencing: Generally speaking if someone is generating electricity and selling it to customers there is a need for an Ofgem licence. However, it is not very clear how the regulations work if someone generates electricity on their roof and sells it to a neighbour if there is a need for a licence. This is because in some cases there are exemptions, each case and business model will have to discuss this with Ofgem. If a private network is built like the Woking Council scheme (2013) there may be less red-tape. '*Community energy*' schemes are seen by interviewees 2 and 19 as a way forward for DC generation, however schemes like that on the Isle of Sky (Energy4All, 2015) are seen by this research as a centralised system even if it is only village wide.

(2) Possible business models: To overcome the difficulty of individuals not being allowed to sell to each other the energy generated, interviewee 19 put forward the following business model: the community puts up the capital for the system via a company owned by everyone, then they as customers pay for consumed energy and then are 'reimbursed' via dividends to offset their bills. He presented another model, whereby external companies like Ovo Energy, Energy Local or Origami Energy in the UK and Solar Century in the USA, who as a third-party business will seamlessly manage the electricity generation. This may be either as owners of the system, using the 'rent-a-roof' (Center For Sustainable Energy, 2015) model or as 'network' managers where they manage the home owners system, on their behalf.

(3) Trade associations: many of the interviewees, (4, 12, 14, 16, 17 and 19) pointed out that the suppliers of renewable energy generating and backup systems, should be the ones to

promote the usage of DC voltage systems. They are in the position to do this via their professional and trade associations, who already have the ear of the media and government. They should work together with network operators to promote low carbon generation.

(4) Some of the interviewees suggested using the media and lobbyists to promote DC voltage systems within government. For further discussion about corporate marketing techniques see the next section.

### **5.10. Theme 6 - Advancing the solution - H3**

In the two previous themes that showed aspects of the ‘*how*’ of the transition to DC, the discussion was about which social networks were part of this transition. However, in the process of a niche technology breaking out into the mainstream, understanding the relationships between people within an institutional network and between different networks and mechanisms of change are important. This is what is called institutional structuration. This theme is about how the mechanisms of actions and information flows help the transition to DC voltage systems.

#### **5.10.1. Using institutional structuration to advance a project**

It has already been explained in Section 3.2.6 above, how an institution in its widest context has been defined within this research and what structuration means. At every stage of the transition process, different institutions will have to be engaged. Whether it is to procure finance, to grow the community, or to gain public opinion, to be successful it is important to understand how different people operate within the framework or mechanism of their work environment, i.e. their institutional structuration. This in essence is about understanding the individual institutional structurations through which the DC project will have to traverse. Most of the interviewees were able to provide some level of structuration to some of the institutions associated with the transition to DC voltage electricity.

Many of the interviewees had spheres of influence beyond their main jobs, as either some sort of committee member, as a consultant, as part of a consortium or within a trade and professional association. This duality of role afforded them the ability to discuss many aspects

of institutional structuration connected to a transition to a DC voltage society, beyond their immediate job. In effect they are ‘*boundary spanners*’ who are people who “...*undertake boundary spanning activities as part of their mainstream job role*” (Williams, 2010). They were therefore able to discuss the structuration of many of the institutions that were identified in the social networks discussed above in Section 3.3.9. Understanding mechanisms of influence is very important. This may be through the media or face to face, knowing on whom to place the pressure, i.e. knowing who has the power to make changes will make the difference between success and failure. It is important to find out who are the correct people to be talking to within an institution. For example, within an appliance manufacturer, the way in could be via the marketing team or product line manager (interviewee 15), the chief technical officer or technical director (interviewee 16), the chief designer or research and development manager (interviewee 14), or the owners/director (interviewee 5). It will be the people in the organisation that are always looking for the ‘next big thing’.

For multinational companies knowing whom at which office in which country is/are the decision makers is very important. An example is Hoover, whose parent company headquarters is in Italy, its European head office is in England, its research and development office is in Scotland, but the actual research and development activities have moved to its manufacturing base in China, where the decision makers are based, yet the decision makers regularly go to the Scottish office for important meetings (from telephone conversation with someone at the company).

Government funds from the science budget may pass through several institutions before getting spent. In the UK this may be via the Research Councils, government departments, different ‘watchdogs’ like Ofgem, the Knowledge Transfer Networks, the Catapults, think tanks, universities, business and others. At each stage where the funds are transferable, a funding mechanism with protocols exists to facilitate the transfer. Understanding these mechanisms and protocols is important in facilitating a transition to DC voltage systems. Interviewee 2, expressed that there is a need for a more ‘*strategic relationship*’ between all the institutions, from the Treasury to the institutions that finally spend the money.

Grants are coded and placed within labelled criteria. What a person who wants a grant has to do is: 1) identify which granting institutions the research project is best aligned with, 2) then

within that institution which funding scheme is best matched to the project and finally 3) be able to show that the research will fulfil the goals set by that institution for these particular funds. This in essence is the structure of a grant application, it is aligning the criteria of the project with the “*regulations, norms, values, culture, actors or practices*”, of the granting institution i.e. by understanding the institutional structuration of the granting institution there will be a greater chance of a successful bid. This is especially important for the DC project as it will initially have to be a ‘responsive mode’ application. Within companies, cost benefit analysis is crucial for a successful adoption of a new product, as the finance department will have to be convinced that there is money to be made.

### **5.10.2. Knowledge transfer**

This is a second stage in the knowledge transfer process and seeks to disseminate information to a wider audience. At this stage there should be a fully functioning pilot scheme that will be the proof that a fully functioning DC home is possible and feasible. So while up to now only a handful of MPs and the specific parliamentary committees may have been approached, it is now time to lobby all MPs and do a planned information campaign. It is also time to bring on board the types of organisations listed above in Section 5.7.1 that have not yet formed part of the coalition building as described in Section 5.7.

Understanding that there is a trend towards distributed electricity generation, is a way to disseminate knowledge about DC voltage systems, as interviewee 17 put it:

*“To set out where the direction of travel is obviously heading, which is towards more decentralised technologies, making the most of storage and flexible demand, that is obviously where things are going to move towards and if you look at some of the big financiers like Barclays, Deutsche bank, City have all come out and said that the future is going to be in the small technologies, utilities are old hat, this is where the entrepreneurial opportunities and the investment opportunity is. Trying to get that message to policymakers will help. Once they understand that the energy system of old is changing, then you can get into a debate about what options we have about making the most of DC, but at the moment there is no understanding of that as an option.”*

Context in knowledge transfer is very important, as interviewee 5 put it: *“For example, talking to a DNO, you are talking about watts, they say ‘we only know about megawatts’ and you are like er er, that is kind of a harder conversation to have because it is so far below their*

*radar as an issue, they are not kind of getting it yet. Is not true of all the DNOs, there are many smart people who do get it.*” Therefore, when discussing how DC voltage systems can save energy, aggregated values over a housing estate or over all households in the country makes more sense to a DNO than just the average savings within one house.

Besides trying to get policy makers onside, it is very important to get the whole supply chain interested in moving in the direction of DC voltage systems. As interviewee 10 put it: *“academia can go to manufacturers, academia will publish papers on DC, manufacturers will pick up these papers and if there is opportunity or they see something there that they might be able to exploit, manufacturers will go to academia and have this explored”*. Although this seems to be a two-way communication, initially academia and research will have to approach manufacturers with a convincing argument for them to build upon.

In 2016 DC voltage is used within the railways and crane industry, but there is only a relatively small number of people who have expertise in these DC systems. When interviewee 3 approached different equipment manufacturers of DC switchgear and system builders, he found that the information about DC and how it would operate at full DC load was *“not joined together”* and what was lacking was education about the effects of DC power, rather than training installers to put together DC systems. Interviewee 5 said the opposite, that electrical installers lacked the knowledge to install DC systems, but it was agreed that the installers were all competent professionals and were easily able to be ‘trained’.

This theme is about building on previous coalition building and disseminating the ideas about DC electricity to those who are needed in the process of transitioning. However, at this stage it is not about public campaigns, it is about putting into place the necessary mechanisms to allow a pilot scheme with real people living in a small housing estate that are only using DC voltage electricity in their homes. Data about energy usage, efficiencies, carbon footprint etc. is still being monitored and may still be feeding the standards network. The fourth stage of the ‘how’ DC will be able to transition is about proliferation into the mainstream and taking over the AC regime.

### **5.11. Theme 7- Taking the concept to the public – W3 and H4**

The initial part (H1) of publicising the advantages and the need for the electricity system to transition to a distributed DC voltage system, takes place as part of the coalition building process, which will take many years. H1 culminates in a house that is used for testing and further research. That stage of the transition process is still taking place within the niche environment that will lead to the development of prototypes and small-scale DC housing developments. Throughout these initial stages of the transition process, it is not only about showing proof of technical and practicality concepts of DC systems (interviewee 6), but it is also about advancing the social aspects, (as interviewee 16 states “...to claim a greener product which is obviously marketable in some countries”), and the ramifications for national agendas.

Knowledge dissemination at the second stages (H2 and H3) is still about transferring knowledge within the niche ‘community’. At the end of stage H3, not only is there a pilot scheme of a small housing estate that is lived in by people in the community, but institutions like policy, industry, standards, education and training etc. have become part of the coalition who are helping to facilitate the transition to a DC society. This last stage (H4) is about getting DC onto the national agenda, it is about gaining public opinion and about winning over the general public, and the policy makers and national institutions that have not yet embraced the DC project. This is what interviewee 6 calls “*proof of market need*”. However, **how** does one win them over?

Note: At this time there is a large gap in the availability of DC appliances and DC home systems technology. Therefore, when looking at this stage of a transition to DC, the interviewees were only able to ‘future gaze’ based on their knowledgebase rather than on direct knowledge of DC systems.

#### **5.11.1. Knowledge dissemination**

This stage of knowledge dissemination is key to winning over hearts and minds. It should be about breaking down the preconceptions and knowledge barriers between the different groups of people associated with the transition to DC electricity. It is about bridging the gaps between policy makers and engineering, between the world of social science and engineering

and between the implementers and the users. It is about showing how distributed DC systems are aligned to the 6 global grand challenges (Institution of Engineering and Technology, 2012), the 'Horizon 2020' program, the UN's global sustainability goals and how such a system can ensure a high level of personal living standards for this and future generations, especially where DC may provide a high level of energy independence and energy security.

So far, which policy makers and government departments will need to be approached and what kind of format to use for the written word has been discussed in Section 5.9.2. However, there is a whole area of marketing DC using corporate lobbying techniques, both face to face and via the media, that must be used to counter the corporate lobbying of those who for whatever reasons think that decentralising the electricity system is a bad idea. These 'nay sayers' do exist, from research produced by the BRE (2002) for the DTI, right to the opposition given by interviewee 20 who is a professor of electrical engineering. Their many reasons for negating the use of DC voltage systems for consumption purposes will need to be countered with the help of specialised marketing techniques.

For example, interviewee 4 was asked the following question: *"What role do you think education of people in positions of power or decision making in the UK plays, do they understand what the advantages of DC power are?"* and he answered: *"No I don't believe they do I also think they hold a lot of ingrained prejudices which goes back to the Tesler and Edison fight and the electrocution of elephants, the fight to win to use AC still carries some legacy today in my opinion."*

Further is the misconception that *"DC is **inherently riskier** than AC, as there are no zero crossing points and 350 V DC would kill much more quickly I suspect than 240 V AC, although in the states 110 V AC so I would suspect there are serious safety considerations, but it is frankly not an area that I am an expert on"*. On one hand, this statement comes from an engineer who sells sub-50 Volt DC systems for lighting and IT, yet he is not ready to scale up the DC system for large loads that may need 350V DC because it is *"**inherently riskier than AC**"* while stating that he is not an expert in this area. Therefore, the task of knowledge dissemination for the proliferation of decentralised DC will have to not only convince the layman but also the sceptical engineers. After all, these notions about DC electricity did not deter the usage of DC in many Manhattan apartments until the early 1960s and still does not

deter the use of DC for lifts, for cranes, within ships systems and for the railways (see Section 2.2.4).

Within DECC, POST and other governments departments “...*there are a bunch of people from large corporates who are seconded in to help on large projects, that is not lobbying in the usual sense but it is influence*” (Interviewee 12). Therefore, while this is not traditional lobbying these experts or interns, who are paid by external bodies, by their very nature, bring the corporate message into the policy arena. Parliamentarians, who as ‘laymen’ require expert opinion to formulate policy and make decisions, invite corporate and academic experts to present information. This is the arena in which the technology champions and reputable messengers must present the case for distributed DC systems, they must become a “*trusted voice*” within policy making, see Section 5.7.1 about coalition building.

Energy policy instruments can be very contentious and the way the media portrays the idea can make or break a policy instrument. A good example was given by interviewee 17:

*“A couple of years ago, the Department for Communities and Local Government decided that if you are going to do any work on your house, if you are going to spend over a certain threshold, then you would also have to put some sort of energy efficiency into it. It was a really good idea, it gets over the initial problem that some people have with energy efficiency and that was taken over by the Daily Mail and called the conservatory-tax and it was scrapped by the end of the week, that is how powerful the media can be. They are the mouthpiece for government policy, that is how most people understand what the government is doing so they are very, very scared about how stuff is going to be written up in the media.”*

Policy makers strive to keep public opinion on their side, interviewee 12 is of the opinion that “...*policy makers are quite reactive to public opinion on energy*” and that “...*the Conservative party are now saying that they are going to end subsidies for onshore wind (in 2015) and I think that is largely as a result of pressure by the media*”. For the DC project to be successful it has to have the media on its side. Therefore, disseminating the message through ‘marketing’ the DC concept is a very important aspect to win over the hearts and minds of both the public and the policy makers.

If the goal is to get DC onto the policy agenda, then not only is it necessary to understand what the present policy agenda is, but to understand the whole process of policy formation from initiation to ratification, this is what has been called ‘institutional structuration’ of policy



making. Furthermore, for the transition to occur the goal of DC must be in alignment with energy policy goals, hence the discussion by this research about energy security and energy independence (see Section 5.6.4). It has to be shown, that not only is DC in alignment with energy policy goals but it will enhance and fulfil these goals. This is what is called ‘technological alignment’, providing technological solutions to social, political and societal needs, see Section 5.8.2.

### 5.11.2. Possible ways forward

Interviewee 3 had specific ideas about how DC could proliferate;

*“It needs to come from the institutions first off with a coherent set of standards, then the educational establishment can take and develop it into courses and modules or things like that, to align them to sustainable technology and then take it a step at a time in the development into the built environment but certainly starting off with the institutions then the education establishments in parallel with some government funding for research which then the universities and institutions can participate in. That is how I would like to see it delivered”. He continued: “...I think it will start to develop naturally rather than it being forced through the adoption of financial change, carbon management and things like that...”*

Within large institutions it was suggested that the IT and energy management managers could be the people through whom DC office systems can be adopted. Retrofit was seen by some as a way to proliferate DC systems (interviewees 1, 4 and 6) but this was only seen as a means to provide electricity for lighting and very low powered appliances, many saw the larger loads still being operated using AC voltage.

As of 2013, the German utilities “...lack adequate business models to commercialize small-scale customer-side renewable energy technologies.” (Richter, 2013). The same applies to Austria (Gsodam et al., 2015). Therefore, as explained in Section 5.6.3 above, as the business model of some of the large UK electricity generators is one with vertical integration, they should be persuaded to go the last step and invest in renewables on people’s homes and on offices, as in the future they “will come under threat from the effects of renewables” (interviewee 12). They could also embrace the ‘third party ownership’ model (Overholm, 2015) which is similar to the rent-a-roof model. If the utilities change their business models this would help in the proliferation to DC.

At this time there is no such thing as a DC appliance market. All electronics are powered via AC voltage and use transformers to provide the DC voltage. Therefore, such a market will have to be built. As interviewee 10 put it “*manufacturers are in business for a profit so if there is an opportunity there they will exploit it or explore it.*” Therefore, putting forward the business case with cost benefit analysis will bring manufacturers in, thus helping the UK economy. Interviewee 15 pointed out that within large appliances there are many stages of voltage regulation to operate the different functions. If the appliance was to be fed with DC voltage it would make the appliances cheaper to manufacture and less complicated.

As interviewee 14 has stated that the government is one of the biggest procurers, this suggests that the first ‘wave’ of proliferation for DC consumption systems could be within the public sector. The government can use its buying power to place orders with manufacturers for DC products that have been specified in a ratified standard. The government could then regulate for a specific amount of new housing built per year to have either fully DC or dual electricity systems, thus growing the domestic market.

### **5.11.3. Users**

Interviewees 3 and 6 pointed out that electricity consumers (users) are not concerned whether their electricity supply is AC or DC, what they care about is ‘will my appliance work if I buy one from a high street shop and just plug it in?’ Secondly, any DC system must operate seamlessly just like the present AC system operates, with almost zero maintenance by the users. Switching a breaker or changing a light bulb is as interactive as it should be. Finally, as many of the interviewees saw DC systems operating in parallel with the AC system, there was concern that the plugs and sockets will have to be, as was in the UK before 1948 and they are in Europe (Fallon, 1976), of sufficient difference in shape that even a child could not plug an appliance into the wrong power socket.

Interviewee 16 pointed to the power of the consumer to affect the success of a product:

*“Obviously the public out there do, people are always looking for marketing information. When they have service failures in the field they are recording that type of information and seeing where they can improve that and try to remove those failure elements from the product. ...if you have a recall it is going to cost*

*you millions. There are consumer groups out there that create campaigns on things, these things do sometimes have an influence...”*

Interviewee 9 put it as follows: *“...the key individuals are in fact what I would call the users. If we can demonstrate an improvement in the level of service and in the standard of service provided by the electricity system people are going to be interested”*.

Furthermore, consumer take-up is a pathway for the successful proliferation of a new technology, as interviewee 5 hoped about the usage of USB devices: *“If that really takes off, as the USB consortium hopes, it will have dramatic effect on the ability to provide DC power to lots of DC devices in the home.”*

It was suggested that DC systems should be looked at like any other consumer product where marketing skills are used to gain market share and successes. Such skills are rare and therefore a professional marketing company/s should be used. As interviewee 6 put it, *“Professional marketers, can create the demand for new products that people did not realise they needed, it is really a valuable skill”*. It will be important to demonstrate to the users all the advantages of distributed DC systems. Some of these are: smaller system, uses less energy, reduced bills, smaller capital expenditure, more resilient to external shocks that cause blackouts and a reduction in harmonic distortion. This can be done through consumer focus groups (interviewee 6) running consumer tests and understanding consumer behaviour (interviewee 15) and having a few DC houses that real people live in (interviewee 19). Consumers can drive demand as interviewee 10 put it *“If users want DC, manufacturers will make DC appliances, it is that simple”* and *“Manufacturers are in business for a profit so if there is an opportunity there they will exploit it or explore it”*.

Initially DC *“will start by appealing to niche markets”* (interviewee 6). These discerning consumers are what are termed *“early adopters”* (interviewee 9, which is in accordance with the second category of Rogers (2010) five adopter categories) and like the adoption of rooftop PV would be the first to change to, or add, a home DC electricity system. Consumers have to feel positive about a brand, product failures and recalls *“cost millions”* and reduce consumer confidence in the technology. For this sector to grow there is a need for across-the-board British Standards to give confidence, both to the brand manufacturers competing against generic manufacturers and to these early adopters. There are many entrepreneurs who are

willing to invest in new skills so that they can take advantage of an opportunity, for example many small businesses invested in acquiring the skills needed to provide Home Energy Certificates. Therefore, there will have to be learning providers to create courses and schemes to 'skill-up' this workforce to install and maintain DC systems.

Consumers act as a voice to lobby for more "greener products". While many are willing to pay a premium for a more 'eco-friendly' product, others are very vocal in opposition to 'eco-unfriendly' products. Therefore, 'eco-friendly' consumer groups can be a conduit to push for, or advocate for the proliferation of distributed DC systems for consumption. Such consumer pressure, together with regulatory authorities initially setting quite low 'green' standards, creates the environment where manufacturers can then compete to drive up the 'greenness' of their products, which allows them to claim that their product is 'greener' than their competitors (interviewee 16). This is the second stage of market proliferation, where the market takes over thus becoming self-propelled. At this final stage (H4) it is quite conceivable that a government may seek to reduce or remove its fiscal incentives, like it did in 2015 with the feed-in-tariffs. However, as the Solar Trade Association has stressed over last decade, removing such an incentive could impede the market (Solar Trade Association, 2015).

If there are readers of this research, who feel that DC has no place and that with all its advantages DC may be a 'solution looking for a problem', interviewee 6 pointed out that in the 1960s when the laser was invented "*the most exciting thing they could think to do with it was bursting balloons because no one had thought of the use for it yet, it was just a party toy, it was just an interesting curiosity. It was a solution looking for a problem. Graphene was a solution looking for a problem. The trick with that idea and product is to look for applications where this could give you some kind of significant advantage either financial or market differentiation*". This is why there is the need to have some DC houses that are used by real people who can demonstrate the real life advantages.

This theme tentatively tries to 'future gaze' to look at some possible ways in which the proliferation to DC voltage systems can happen. Many of suggestions from the interviewees are possible and will work in parallel to help the transition along its pathway. The question now is how long will such a transition take and what are the milestones along the way?

## 5.12. Theme 8 - Timeline dependence – W5

One of the goals of this research is to develop a timeline through which a transition to DC may take place. In Section 1 of the Global Energy Assessment Report (GEA, 2012) the timelines given are 2030 and 2050, which is a timeline of approximately 40 years from the time the report was written. Therefore, within global challenges, which include energy and electricity, a time horizon of 40 years is seen as reasonable. A major market transformation like that from AC to DC is very complicated and will have parallel processes happening at the same time. A list will be made from the interview data showing the duration for some of the intermediate components of the transition to DC systems and then they will be compiled into a full timeline. Presuming that the DC project will begin in 2017 the timeline will go to 2060 (see Figure 6.4).

In this theme, timeline data is grouped according to different goals that may occur at specific times or at multiple times along the timeline. The timeline sequence will generally follow the milestones that develop out of the themes.

Interviewee 3 was working on a feasibility study to implement a DC data centre for the company he worked in. At the time of the interview it had taken 18 months to convince the company to do a pilot scheme. He envisioned another 18 months for it to become operational. DC data centres are a tried and tested technology and have been in operation for a number of years. This may be why interviewee 3 expects to implement his project within 3 years. However, how long would a prototype DC house take given that much of the technology, especially the higher powered ones do not exist in a form that can operate only using DC voltage?

*“I think that will be 10 to 15 years away at least before we get new homes that are constructed with pure DC only” (Interviewee 3).*

The Royal Institute of Chartered Surveyors have a Building Cost Information Service that uses a 30 years cycle for the lifetime of an electrical installation (BCIS, 2007). Therefore, it is possible that the houses that will be rewired at the time that DC systems start to proliferate for AC could take another 30 years to get rewired for DC.

### **5.12.1. Funding**

As explained above there are many stages of funding. Initial funding is needed for bass-line technical research within an institution like a university, which includes proof of concept research and building a demonstrator. It is estimated to get accepted by a university without research council funding could, depending on the time within the academic year, take up to a year. This year could be used for preparing and presenting a responsive mode proposal for Research Council funding, which, if accepted, could take up to six months for the research council to release the funds (interviewee 2). The first stage is to produce a single DC laboratory house which could take up to five years. The second stage would be to fund DC systems installed into houses that people actually live in (like the SoLa Bristol project) this stage could take up to a further four years to get funding, install and gather data. Then funding would be needed to produce standards and to provide market incentives for DC proliferation, how long this could take is not known but three to five years is reasonable. The time it could take for a research council to accept DC as part of their five-year plan, so that the research council themselves will make ‘calls’ for funding can be two to five years depending on the development and public profile of the DC project (interviewee 2).

### **5.12.2. Standards**

As explained there are many levels of standards, top-level European standards down to plain regulations and the DC project will need all of them. Top-level standards could take up to 5 years to ratify. Lower level standards like industry initialised ones could take up to 3 years to ratify (interviewee 16). While things like a new DC CoP can take up to 2 years to ratify. Some of these do not develop in tandem and therefore their timeline will be sequential. The building regulations are reviewed every 3 years (interviewee 14). Therefore, depending on the review cycle, once DC is part of the agenda of the regulatory authority’s agenda, 3 years is the longest it will take to get DC fully integrated into the building regulations.

### **5.12.3. Production of DC appliances**

A new product feature could take up to 2 years, but for a completely new architecture it could take up to 4 years to go through the pipeline of a brand name appliance manufacturer's system before being released on to the market (interviewee 15). Many appliances that are either electronic or have electronic components within them, already use internal DC voltage regulation. Therefore, they may be able to be transformed into DC only products within a few months, most of which could be taken up to go through the new certification process required when modifications are made to a product, rather than due to having actually re-engineered the product (interviewee 15).

Interviewee 5 stated that it took 3.5 years for a complex DC technology to get into the market, while a simple USB powered product took 6 months. So after manufacturers have been convinced to make DC products it may still take many years to get into the market.

### **5.12.4. Policy decisions**

According to interviewee 10 the UK policymakers are about 5 years behind the leading edge of energy policy, this was blamed on powerful lobbying, which seeks to keep the status quo and to allow industry to self-regulate. Interviewee 15 pointed out that industry needs a 10-year stable horizon to be willing to invest in new ideas, develop and produce them and to enjoy the profits of their success. However, over the last decade UK energy policy has kept changing, which has created uncertainty within industry which slows down innovation and development.

Governments in the UK are for a maximum of five years, therefore the time horizon for politicians is five years (interviewee 13). This is seen as a problem as the time horizon for research is much longer, for example for the DC project it is 20 to 40 years. Five years is the same time horizon used by the Parliamentary Office of Science and Technology for their horizon scanning research that is looking into trends in several major policy areas. The DC project may have to go through a regulatory process to be governed by a government body like Ofgem. Such a process could take a *“couple of years at least”* (interviewee 19).

From interviewee 16's experience it took two years to get an industry consultation to occur, which was just to gain consensus about the technical governance of the electricity system and for the position of a “*systems architect*” to be agreed. Therefore, how long will it take to reach a consensus for the need for DC distributed systems, which is a major market transformation? It may take much longer than two years.

#### **5.12.5. A national project development cycle**

The transition from British Standard 546 for the round pin plugs to British Standard 1363 for the flat pin plugs took from 1934 to 1947 which was 13 years. (Latimer, 2007). However, BS 546 was amended in 1950 and according to the BSI website as of 2012 it was still ratified. This shows that both standards operate at the same time, even though in the UK it is not widely known that it is still legal to use round pin plugs that comply with BS 546:1950. When the flat pin plug was first developed is not known. However, in May 1939 there is a discussion in the IMEA journal (Stanley, 1939) that at least before March 1938 it was proposed. How long the flat pin plug took to become ubiquitous is not known, it is thought it took at least 20 years. This gives an approximate timeline from when the flat pin plug was first suggested, which was before 1938, to when it became ubiquitous of between 20 to 30 years. This is what interviewee 6 said:

*“I remember living in houses where you had two or three different types of plug, some round some large some small some square. And the square plugs didn't really come in and were fitted as standard probably till the early 1960s. The house, I now live in, we moved in 1983, still had round pin plugs in some of the rooms. And incidentally, there is a standard for DC distribution, I believe it is based on the round pin plug”*

Interviewee 12 discussed the first stage of the development cycle for smart grids, which started in the late 1990s and by 2010 had procured Low Carbon Network funding for a demonstration project. It has taken almost 20 years yet smart grid technology is still not (in 2016) pervasive on the national grid network. Given the stage of development of power over USB and Ethernet, the fact that electronics are embedded in every electrical device, sometimes just for control purposes and given the research and development work already being done to put DC into the office environment, Interviewee 3 said that “*I think that it is 10 to 15 years away at least before we get new homes that are constructed with pure DC only*”.



This research understands that this ‘15 years’ as the time it will take to reach the small housing estate stage but not to nationwide proliferation.

### **5.13. Summary**

The information gathered from the interviewees has given a better understanding of the processes that will be needed to be implemented across the whole sociotechnical electoral system in order for it to be able to transition to DC voltage systems. Some of these processes were known to exist from the theory, but the data from the interviews added details, sequencing and timelines to these processes that was not seen within the available theory and secondary data. This data will now make it possible for a construction of a transition framework that will include a transition pathway and a timeline.

## Chapter 6

### Discussion

The information gathered from the interviewees and secondary documentation has given a better understanding of the processes that will need to be implemented across the whole sociotechnical electricity system in order for it to be able to transition to a DC voltage system. Some of these processes were known to exist from the theory and the interviews added details, sequencing and timelines to these processes that were not seen within the available theory and secondary data. This data will now make it possible for the construction of a transition framework that will include a transition pathway and a timeline.

This chapter will revisit the aims of this research in light of the UN's 17 sustainability goals for 2030. Before the transition can begin, a small team must be built. To do this knowledge transfer will have to occur. It will look at who to target, with what knowledge, and the dialogues within and between the institutions, i.e. their institutional structuration. A potential transition framework with a timeline will be developed from the data and the barriers to, and enablers for, the transition will be discussed. Finally, the viability of the transition taking place, in light of it being looked at as possibly being a wicked problem, will be discussed.

#### **6.1. The global challenges and electricity**

When this research started in 2012, the Global Energy Assessment report (GEA, 2012) was used to identify important global challenges facing humanity in the 21st century. They are presented and discussed in Chapter 1 above. Over the years, international institutions like the EU Commission and the UN have focused on and expanded their list of challenges. These have been incorporated into the EU's Horizon 2020 project (European Commission, 2011) and the UN's '*17 Sustainable Development Goals*', which are part of their '*2030 Agenda for Sustainable Development*' (United Nations, 2015): these are presented here in Figure 6.1 below. It is understood that many of the UN's goals are directed towards developing nations and may not be pertinent to the UK, however the many that are, have been discussed in Chapter 2 above.



Figure 6.1 The United Nations 17 Sustainable Development Goals for 2030

The pervasiveness in the use of and reliance on, electricity for humanity's every day functions cannot be underestimated, even for nations that are in the developing world (see Section 2.3 above). This research identified distributed direct current voltage electricity systems, for supply, distribution and consumption, as a possible solution to at least alleviate some of these challenges. Following the data gathering stage of this research, goals 1 to 13 which have been highlighted in bold in Figure 6.1 have been identified as having some connection to electricity and therefore could possibly be alleviated using distributed direct current voltage electricity. Those like energy poverty, health, food and water, carbon emissions and those associated with sustainability, are more directly connected to the availability of electricity. Gender equality,

equality between nations, education and poverty are indirectly connected to electricity and therefore less impacted by distributed electricity systems.

This research is based on the need to find a solution for these global challenges. The research question was ‘how can this transition be accomplished?’ To help understand how a transition of this magnitude can happen, the Multi-level Perspective (MLP) on Sociotechnical Transitions was used as the theoretical framework. What this research seeks, is a transition pathway whereby the DC technology can fully develop within the niche and to show the mechanism whereby DC systems can proliferate to the point that it will not only break into the sociotechnical AC electricity regime but will also be able to become the dominant technology.

## **6.2. Which transition process described by the MLP theory is best for this transition?**

With reference to Figure 6.2 below, the process for a technical transition takes place on three levels. Firstly, new technology is developed within the niche, secondly, a transition occurs within the incumbent regime, which transitions to the new regime, and thirdly, if the transition has succeeded it should have relieved the original landscape pressures and also influences the landscape as it is now a new regime, (dashed arrow on top right). However, it is important to recognise that the actual transition occurs after the new technology is developed and takes place within the regime. The **incubation period** includes the three phases that will be discussed, namely: (1) proof of concept, (2) prototyping and (3) a pilot project.

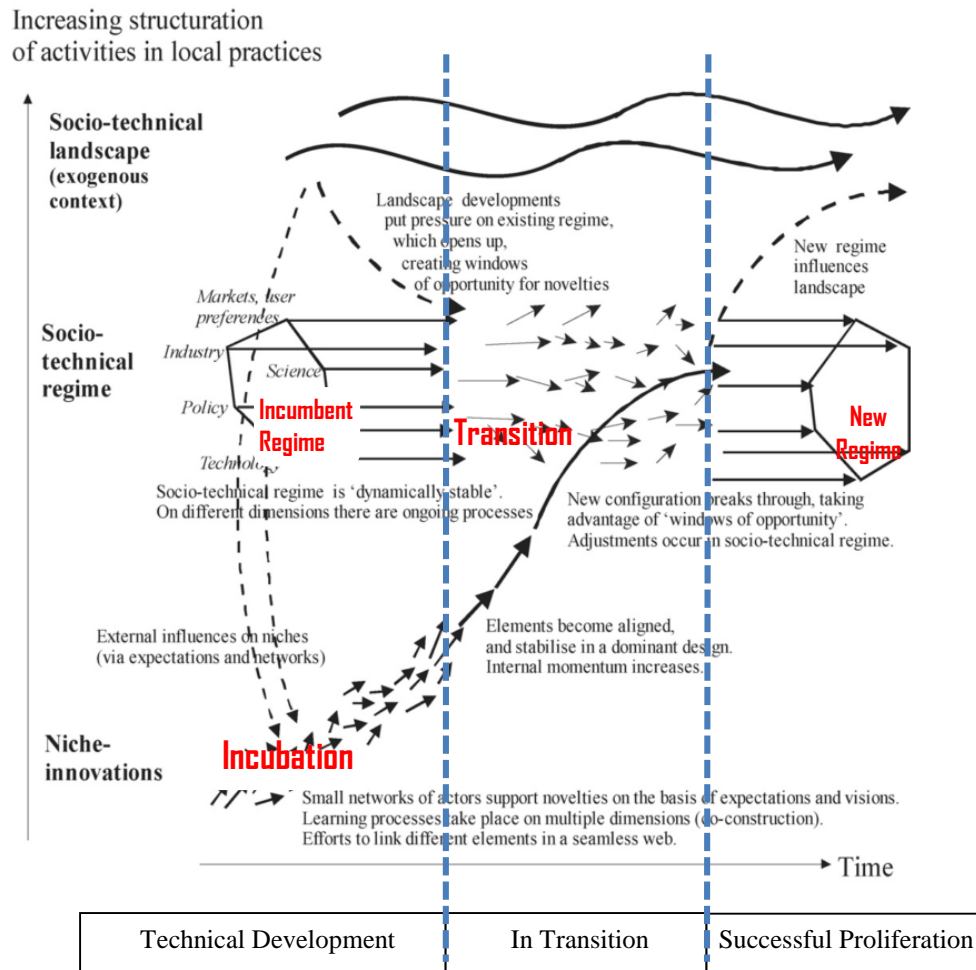


Figure 6.2 How a technical transition takes place  
(Adapted from Geels and Schot, 2007, Fig 1).

A transition implies an incumbent regime and a new regime. The question is what form will the transition take? As stated in Section 3.2.5, Geels (2011) gives 4 possible transition pathways: (1) *Transformation*, (2) *Reconfiguration*, (3) *Technological substitution* and (4) *De-alignment and re-alignment*. In 'Transformation' and 'Reconfiguration' transition pathways, the niche innovations are not or were not able to develop as a competitor to the incumbent regime and as such do not lead to an entirely new regime, but rather to a changed one. While, 'Technological substitution' and 'De-alignment and re-alignment' lead to a completely new regime. The question now is which pathway is most suited for a transition in the UK from AC to DC? It has already been discussed by the interviewees that a position whereby the UK will completely transition away from its centralised AC system is untenable for all the reasons stated in Section 5.6 above, (Theme 2).

The fourth transition pathway of ‘*De-alignment and re-alignment*’ whereby “*The regime experiences major internal problems, collapses, erodes and de-aligns.*” (Geels and Schot, 2007, p. 408) which eventually leads to a new regime, cannot happen in the UK as long as there is a centralised topology to the electricity system. Similarly, pathways 1 and 2 ‘*Transformation*’ and ‘*Reconfiguration*’ leave no room for the UK to completely transition to a DC voltage system, as by definition, the implication is that the new regime will be a centralised AC system incorporating fully independent buildings that have DC systems. This leaves ‘*Technological substitution*’. This transition pathway fits the model of the all DC home as far as the internal electricity system is concerned, i.e. DC will replace AC within the built environment but, as has happened in Germany, will not displace the centralised AC system. Therefore, from the point of view of the incumbent AC system it may have to change but it will not be ousted by DC, unless distributed generation technology becomes a “*disruptive technology*” (Bower and Christensen, 1999; Eisen, 2010). So what type of pathway does the MLP theory suggest for this transition?

Geels in his 2007 paper actually brings a fifth pathway that is not in his 2011 paper. In his paper (Geels and Schot, 2007, p. 413) Geels notes: ‘*a sequence of transition pathways is likely*’. In his discussion this comes out from a ‘*disruptive change*’ caused by landscape developments. If this transition pathway is best suited for the transition to DC voltage systems, then what would this ‘*disruptive change*’ be? This research has not explored this and leaves it for further work.

From the theory, the transition pathway for the transition to DC voltage systems will be **technical substitution** helped by a landscape **disruptive change**, possibly followed in the future by further **technical substitution** or **de-alignment and re-alignment**. Figure 6.3 below shows how a technological substitution aligns with a landscape disruption to form a transition.

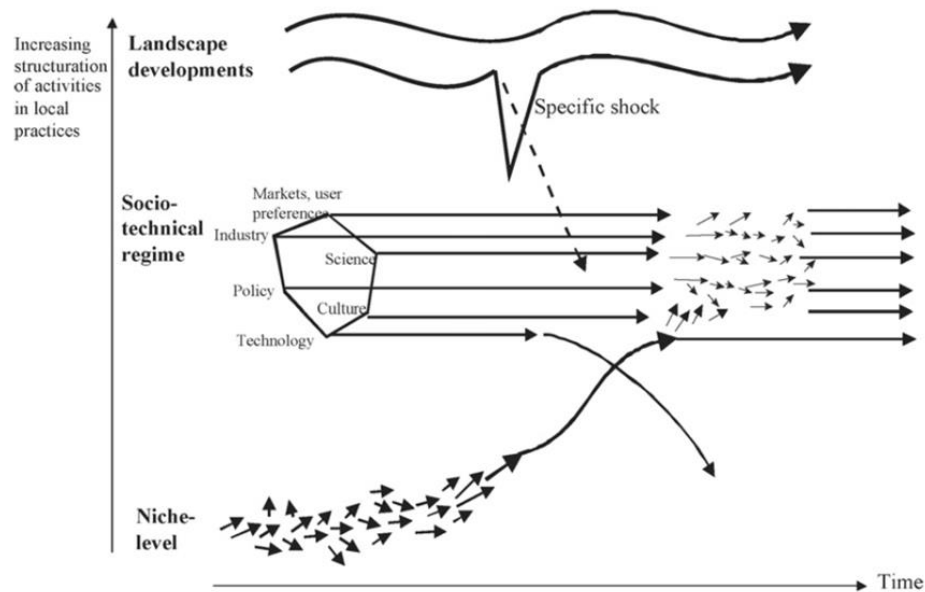


Figure 6.3 Technological substitution and landscape disruption transition pathway (Geels and Schot, 2007, Fig 8).

### 6.3. Knowledge transfer and the discussion surrounding the need to transition to DC voltage

Initially, through knowledge transfer, it will be important to gain the trust and help of the many people needed to form the coalition that will help this transition to be successful. Then the wider world will need to be ‘convinced’ that DC has its merits and should be embraced. This knowledge transfer process is about engaging with the intellectual discussion surrounding the technology and social ramifications that DC can bring. This is W3 and is the ‘Why should this transition take place?’ and is part of theme 2 above (Section 5.6). The details of the discussions surrounding the transition to DC voltage are in Section 2.5 above and include:

- (1) What advantages a **distributed** supply of electricity has over a **centralised** system
- (2) The advantages of **DC** voltage systems over **AC** voltage systems
- (3) How DC can enhance a country’s **energy independence** and therefore provide **energy security**
- (4) How a **city’s resilience** can be enhanced through distributed DC systems

Further to this is the history and availability of DC systems and products that are encapsulated in Figures 2.4 and 2.5 (see Section 2.2.5 above) and how DC impacts the UN's 17 Global sustainability goals. This type of knowledge transfer is ongoing throughout the transition.

Fundamental to any discussion about the transition to DC is that it is a multi-disciplinary/interdisciplinary project which directly affects many societal problems and touches on many more (see Section 2.2.7) including its importance for cross Council research funding (Section 5.8.1). Therefore, the knowledge dissemination must include the many social concepts that are discussed in this research. The technical debate about DC specifications, such as what the DC voltage should be or for the design and materials of the DC technology itself, must be left to emerge from strong technical research that is not commercially driven. Otherwise it is possible that the *"technology which first makes large advances along its learning curve will emerge dominant."*(Cowan, 1990), even though it is not optimised for minimal power consumption, losses and carbon footprint, see Section 3.2.7 for a further discussion about technical lock-in.

Decision makers operate within institutions that have structuration. Therefore, for a successful transition to take place there will be two hurdles to overcome: one is to bring on board the decision makers and the other is to negotiate the institutional structuration that surrounds them. There are therefore three roles that knowledge transfer plays: (1) to inform people so that they become advocates and enablers for the transition. (2) To provide decision makers with the ability to be able to negotiate, and where necessary change, the institutional structuration that surrounds them, so that it will enable the transition. (3) To create bridges between different institutions within different social networks that will enable the transition to be successful. The question is, is this a straight forward process or are there difficulties?

#### **6.4. Institutional structuration, a gap in the literature**

Although the MLP theory can relate to the actors and to dialogue (Section 3.3.8), when discussing historical transition pathways in case studies of length of 50 years or more, the *"technical and social elements"* are identified in the literature at the regime-network level (Geels, 2014b), but not on the level of institutions and their structuration is not detailed. Therefore, within the MLP's theory the general principles for a (historical) transition are



identified, but institutional structurations needed for future transition pathways are not. That is why in Section 3.4.3 above, information about institutional structuration within and between the institutions of the social networks of the electricity system was identified as a gap in the literature. To identify institutional structuration and the ‘dialogues’ that help span the boundaries between different institutions the interviews were conducted.

Every institution has its own internal structures whereby changes can be initiated, discussed, ratified and implemented. Institutional structuration is part of ‘advancing a solution’ which is theme 6 and formed the H3 how. The interviewees discussed aspects of the internal structuration of their individual institutions. These are individual to that institution yet reflect industry or sector wide structures. It was not possible via the twenty interviews to be able to understand the whole institutional structures of all the institutions that may be involved in the transition to DC.

However, what was learned was that for successful transitions to take place, understanding institutional structuration properly, must be part of all transition plans. Furthermore, the links between different institutions and the ramification of the outputs of one institution on other institutions, due to a transition to DC systems, must be well understood to ensure a successful transition. The external structuration of these institutions has multiple integration points between institutions in the same network and between other institutional networks. Therefore, all the networks of institutions, as described in Figure 3.5, are interlocked and have interdependence.

So far this research has identified; who some of the decision makers are, what some of the key institutions are, how the transition needs to be negotiated and it has identified the themes that will be the building blocks for the transition, now it will bring all this information together to identify a possible transition pathway for DC voltage to transition.

## 6.5. An idealised transition pathway

### 6.5.1. A timeframe for the timeline

A very fundamental question to any transition is how long will it take? Geels has carried out research into many historical transition events, many of which have had a very long transition timeframe, see Section 3.1 for many of these case studies. His research looked at what he called ‘*aggregated patterns*’ over time periods of more than 50 years (Geels and Schot, 2007, p. 414). From the many case studies he has carried out, it is therefore expected that a transition to DC voltage should have at least a 50-year timeline. Given that renewable generation systems have already proliferated and only wait for technical maturity and given that some DC systems already exist in the form of Ethernet and USB, this research has tentatively set a timeline of 43 years to 2060 for the full proliferation of DC electricity systems.

The ‘When’ (which is the W5 of the data analysis) of the transition can be represented by a timeline which is based on the data gathered and is represented by Theme 8 (Section 5.12). Many case studies within the transition literature, including the many papers of Geels are historical. The innovation of this research is that it uses the MLP transition theory as a tool to explore a future sociotechnical transition, where the initial concept and goal, distributed DC systems is understood, but the transitions process and pathway, while based on case study data, is more horizon scanning than dealing with known facts. Therefore, this research can only present a theoretical transition pathway with a tentative timeline, which could be said to be an ‘*idealised* transition within an *idealised* timeline’. One cannot know the future therefore, there will have to be a level of arbitrariness within the idealised transition timeline, as this research is an intellectual experiment into a future transition and is open to exploration. Therefore, the timeline is explorative, but based on information from the data gathered to help in the understanding of the sequence of phases in an idealised way. The whole transition timeline is represented in Figure 6.4 below. It shows the key phases of the transition along the top and the different sub-processes that take place throughout the transition along the left side. The key components of each process together with some key milestones, denoted by a diamond (◆) are shown for each phase of the transition.

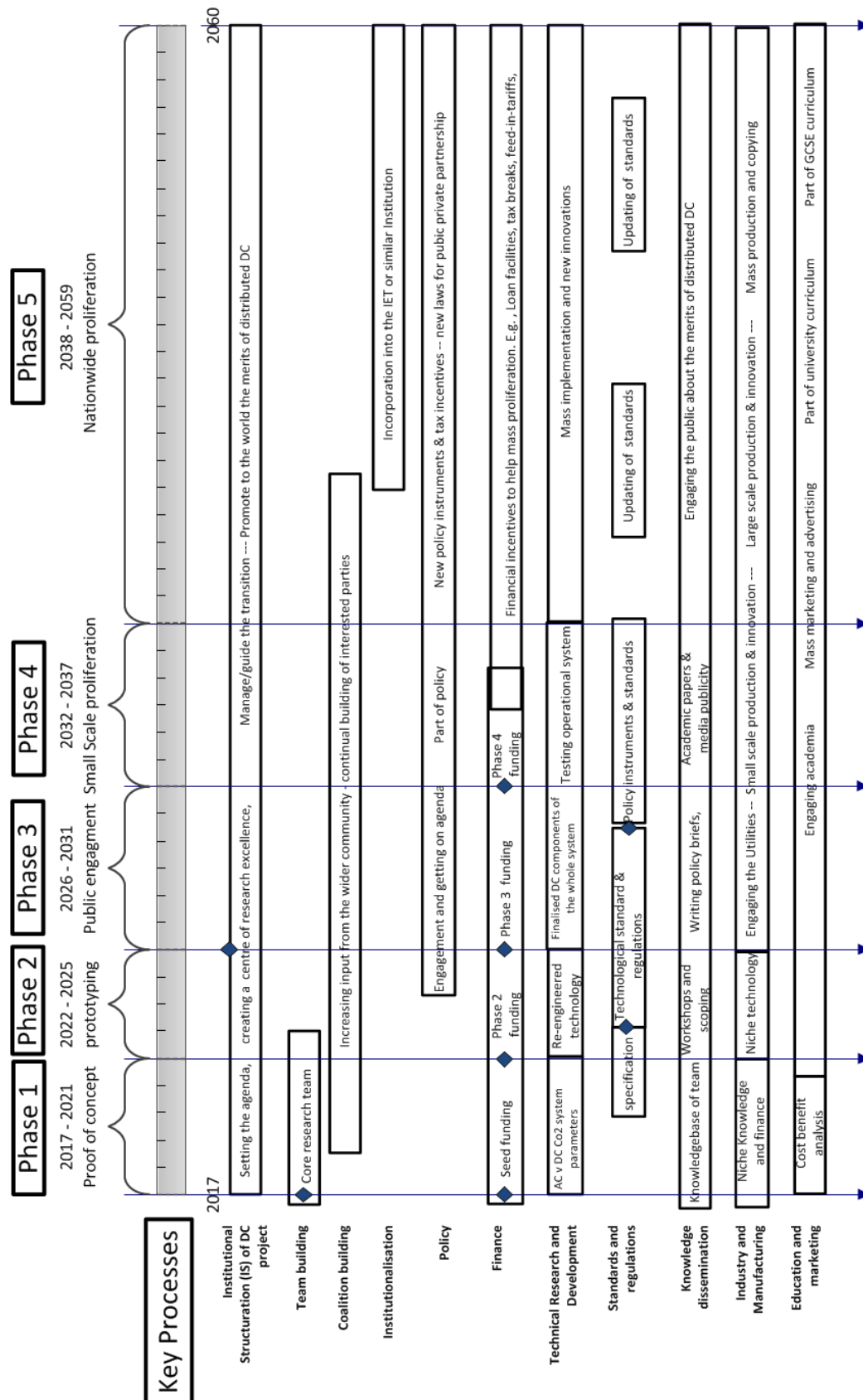


Figure 6.4 The timeline for the transition to distributed DC voltage systems.

### **6.5.2. Sequencing the phases for the transition**

The question is should energy policy be reactive or proactive? Does it have to take into consideration possible weaknesses in the electricity system and take pre-emptive measures or should energy policy only react to external landscape pressures once they are in existence? These two approaches tackle the problem from different angles. The reactive approach is a top-down approach, where decision makers make macro changes to the system, usually on the supply side, to provide a solution and then lets the market sort out the technical details. This research advocates the pre-emptive approach. The transition to DC is a proactive pre-emptive policy to build into the electricity system, energy security and energy independence, which should then provide a high degree of city resilience. This approach is a bottom-up approach, that seeks to change the way electricity is used by first changing the consumption system, then the electricity distribution system within the built environment and finally the supply system. The sequence of the phases follows that of a new product development as presented by interviewee 6.

### **6.5.3. The phases and processes of the transition**

Interviewee 6 showed that there are stages in the development of a new technology. These are: (1) proof of concept, (2) prototyping and (4) a pilot project. These are the three generalised stages which Murthy et.al (2008, Figure 2.5 call *pre-development*, *development* and *post-development* (2008, Figure 2.5). Between a prototype and a pilot project that operates within the public arena, there will have to be (3) public engagement with many stakeholders. With successful deployment of small-scale and then large-scale pilot projects, a national rollout program (5) can begin. The length of time each phase will take to be completed will be explained below when each phase is discussed separately. The five phases of the transition are shown in Figure 6.5 below.

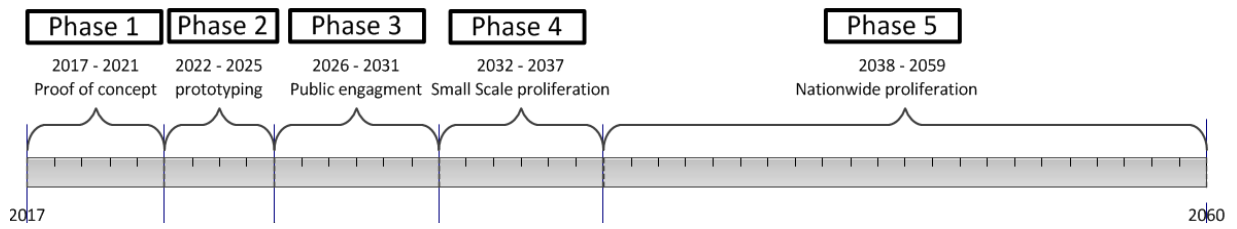


Figure 6.5 The five phases of a technical transition.

There were many codes generated by the interview data that made up the eight themes, each of which represents one or more of the ‘5Ws plus H’. Some of the codes represent processes that are ongoing throughout the transition e.g. finance, knowledge dissemination and institutional structuration. While others are intermittent such as: stages of the technical development, standards, education and marketing. Table 6.1 shows within which phases the themes operate.

Table 6.1 How the themes and phases coalesce.

Theme	5Ws plus H	Phases						The Themes
1	W1& 2	1					What, Where	The technology in the UK
2	W3	1	2	3	4		Why	The intellectual discussion
3	W4	1	2	3	4	5	Who	Coalition building
4	H1	1	2				How	Developing a niche technology
5	H2			3	4		How	Second stage project development
6	H3			3	4	5	How	Advancing a solution
7	W4 & H4	1	2	3	4	5	How to deal with Who	Advocacy of a concept
8	W5	1	2		4		When	Time dependence

Before anyone would sanction a nationwide rollout of DC systems, such systems would have to be proven within a community pilot project to be safe and beneficial. However, before that could happen, a set of standards based on tested prototypes would be needed. As the phases within this transition have to work in a particular sequence, the transition process from proof of concept to nationwide rollout, can be said to have path dependence (Liebowitz, 1995) as the latter stages cannot begin unless the previous phase has completed successfully. There are points in time throughout this transition at which a certain process or milestone must have been reached otherwise the transition will not happen. One of these is funding, without

funding the research cannot take place and according to interviewee 15 without standards manufacturers will be very reluctant to put resources into producing DC appliances. This puts into the transition time dependant processes that have to be completed in a particular sequence otherwise the transition may be stopped in its track, or be by a particular time otherwise it will be delayed. See theme 8 Section 5.12 above for more details.

The data gathered indicated that there will be many smaller institutional transitions, that together will form the transition to DC systems. These transitions will take place throughout the five phases listed above and are categorised as processes, in Figure 6.4 above. These processes have been gleaned from the data gathered and inform who will facilitate the transition and how it will be carried out. Some are time dependant, while the beginning and end dates for some are not known, or are ongoing throughout the transition. All that this research can do is give each process a tentative timeline that will move as the transition takes shape. As a process develops there may be lag or a leap in the beginning or the next part of the process, however for clarity there are no overlapping timelines within the processes.

As there is still a discussion, whether the goal is the DC office or the home, it will be logical to initially target the home as all the types of electrical loads that are in the office have equivalents within the home and the home has many that are not found in the office. Logically, a large office block with social and catering facilities will use more electricity than the average home and therefore the home could ultimately prove a better place for a full low powered DC system than a large office, this should therefore be the proposed focus of the DC transition.

There is also the question of what societal needs the DC project seeks to deal with. The outcome from this discussion will also affect the content of the prototype and pilot. If, for example, the DC project is geared to only help UK energy policy and the global challenges, then the emphasis must be on showing how it fulfils these needs. If, however, DC is directed specifically to give advantages to the users by providing energy independence with security, then it does not need to tick the boxes for all the energy policy or global challenges criteria. Alternatively, as this research advocates the DC design, which focuses on the goal of energy independence and security, it should also be able to be a solution for the UN's sustainability goals.

#### 6.5.4. Phase 1 proof of concept

#### 6.5.5.

Who will be responsible for the implementation of the DC project? Theme 3 has shown us that it will be a coalition of many people, therefore perhaps it will be a committee steered/headed by a high profile individual who is a ‘reputable messenger’. Similarly, a committee with a prominent chairperson was the process by which the standard for the flat pin plug came into being (Latimer, 2007). The chair of the committee should not be confused with what Interviewee 19 called a “systems architect” (see Theme 1 above Section 5.5). Many ‘Systems Architects’ will operate within the phase 4 and 5 to design and implement the actual systems and not within the incubation stages of phases 1 and 2 of design and development. The term ‘governance’ of the DC project at phase 1 means, that its directionality and coordination will have an emergent character, which will arise from the interactions between the multiple actors within the committee and is steered by its chairperson (Verbong and Geels, 2007).

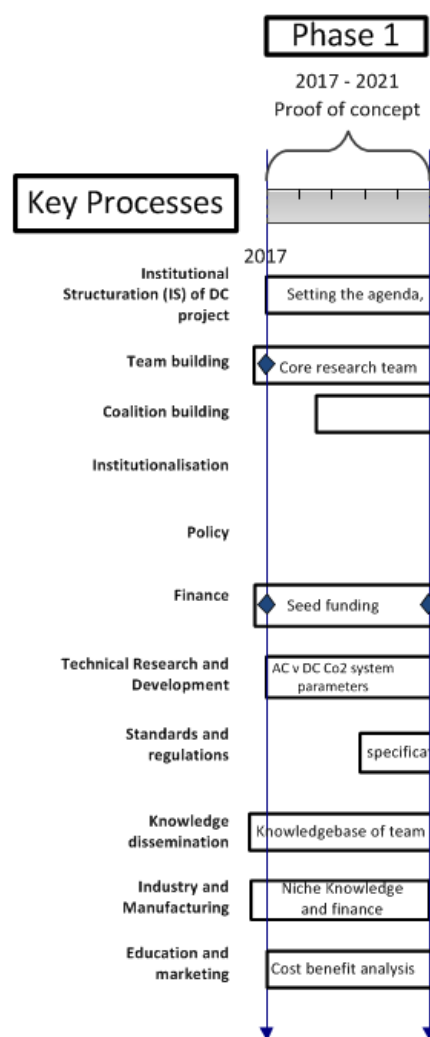


Figure 6.6 Phase 1 of the Transition

Dodds & Demoullin (2013) looked into the feasibility of the UK converting from a natural gas system to one where the gas infrastructure only transports Hydrogen. Within their paper they discuss the transition in the 1970s from town gas to natural gas. This transition was overseen by the UK Gas Council who decided to switch the entire country over to natural gas over a 10 year period (Williams, 1981). Dodds & Demoullin point out that the transition to natural gas had an advantage over a modern transition such as to Hydrogen, in that the production of town gas was largely decentralised.

This made it easier to isolate a small proportion of the town gas network and convert it to natural gas, with streets losing supply for only one or two days. The 1970s gas transition had another advantage in that it was operating in a regulated market with the UK Gas Council having the governance structure to oversee such a national transition program. However, at this time the electricity system in the UK operates in a de-regulated market, without a centralised governance structure. Therefore, if a transition to DC is to be successful it will need a strong governance structure.

Before research can begin, a core team will have to form, with a technology champion at its head. The team will not be starting from scratch, as some of the conceptual work has already been carried out and some of the DC technology already exists. The transition timeline is said to start with the commitment of the core team to the project, however, for this to happen some of the core processes will already have begun, as is shown at the left of the timeline in Figure 6.6 above. The initial role of the core team is to set the research agenda, which will be its institutional structuration. This will be part of the funding proposals that will be put together in order to secure seed funding (see Theme 4 Section 5.8.1), because as many of the interviewees put it, the initial hurdle will be to raise funds, without which nothing can happen.

The research agenda should include: if the goal for the project is the home or the office, which electrical loads will be re-engineered for DC, within which auspices the research will take place i.e. university, or other research institute and which problems will the initial research seek to alleviate in which social networks like policy and standards, etc. A focus on the interdisciplinary dimension to the initial research will have to be emphasised. This will be what is called aligning the research to the criteria of the funding institutions see Section 5.8.2. Making a proper funding proposal is time consuming and has a cost; this is why the funding timeline begins even before the beginning of the transition timeline. Even if the core team work voluntarily, there will be a financial cost before this date. Many start-up companies flounder through lack of cash (interviewee 6). Therefore, cash flow throughout this transition is fundamental to the smooth operation of this transition and causes time dependence to each phase, which must have the funds to proceed.



The core team will bring to the project knowledge and a network of contacts. It has been suggested by interviewee 14, that the core team should have as much as possible a cross-section of skills and knowledge base, like that within a Standards Committee and should include industrial partners. Within the proof of concept phase, connection should be made with home appliance manufacturers to get their expert input into the design of everyday appliances.

The output from this stage should be a demonstration of the advantages DC systems have over AC and some system parameters that will go into a DC specification, e.g. a DC voltage for the system. One of the goals of this phase is to remove all the AC voltage components from the appliances and replace them with components that can operate using DC voltage electricity. Part of the adaptation should be to optimise each appliance such that it operates at its optimal power consumption with minimal losses. Then their power consumption and carbon footprint can be measured. From all the different power ratings of a large selection of DC appliances, which by their nature should be operating at different voltages and currents, a decision will have to be made as to what should be the best DC voltage for usage with all appliances. All the appliances will have to be re-designed to operate at this specified voltage, to verify that the new DC voltage standard is appropriate. In AC electrical systems the voltage is fixed at 230 V and three gauges of electrical cables are used to provide three current levels. The circuit breakers will usually have 5 Ampere, 15 Ampere and 30 Ampere fuses. As the DC voltage will be very low for very low powered devices and much higher for white goods, at this conceptual stage, two or three DC voltages may have to be chosen. It may be appropriate to include smart control technology in all appliances as has been advocated in previous research (Kinn, 2011b). Besides the appliances, the DC mains system and voltage regulation systems will have to be specified as a written specification. The proposed key processes within phase 1 are set out on the left of Figure 6.6 above.

While interviewees 8 and 9 have said (see Section 5.6.2) that their DC system had economic advantages over an AC system due to the reduction in harmonics and a lower energy consumption, other interviewees stated that this advantage was minimal. Therefore, within this phase more rigorous bench testing will have to be carried out, to compare and contrast

different parameters of AC and DC systems. A cost benefit analysis, which should include social dimensions will have to be produced to show if AC or DC is more socio-economic, not just purely in financial terms. It will have to be made by the end of phase 2 in order that it can be used within phase 3, the main public engagement phase. Therefore, throughout this phase and the next, data will have to be gathered about any cost increases or savings and societal benefits or costs, in order to make a proper cost benefit analysis. The duration for this phase is tentatively given five years, as this has in the past been the time limit given by the funding bodies for a given funding-round.

6.5.6. Phase 2 prototyping

As with Phase 1 new funds will have to be found to pay for this phase Figure 6.7. The prerequisites for this phase are: an agreed and specified DC voltage/s for the home and data that shows what the sociotechnical and socioeconomic advantages are for the usage of DC voltage systems. In this phase all the appliances will have to be reengineered to the new specified voltage or voltages and whatever specifications are appropriate will be written. This is the phase in which the appliances should begin to take the form of home appliances and not laboratory test appliances. Within this phase the DC components should come together to create a prototype DC house. This house according to interviewee 16 should be within a university and be more a laboratory than a liveable home. To do this close collaboration with industry and institutions like the IET and the Association of Manufacturers of Domestic Appliances should occur. This is the

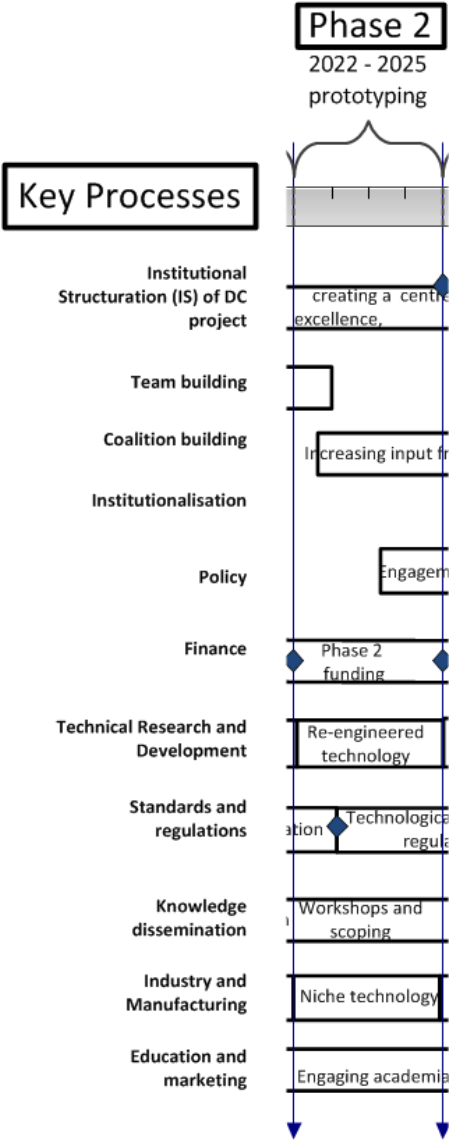


Figure 6.7 Phase 2 of the transition

beginning of taking the project out of the sole auspices of a university and into an industrial setting. It is not possible to determine exactly when the team, becomes a coalition (see Section 5.7.1), however, it is understood that this could be said to occur when people outside the team, working ‘off site’ become involved. Therefore, it is very possible that the coalition can emerge as early as the prototyping stage.

The results of phase 1 testing have to be published, especially the proposed specification for the DC voltage, as this has to be accepted by a wide range of institutions, if it is to emerge as part of a ratified standard. These standards will be ‘low-level’ standards that are driven by the technology and should include the whole list presented in Section 5.9.1 above and show how it will integrate with USB and Ethernet standards. This publicity will usually begin within academia and perhaps niche media, or industry magazines and websites. This is part of the process of creating a research ‘centre of excellence’ which will be the catalyst to engage and disseminate knowledge to the policy makers and a wider audience. DC systems architecture and understanding all aspects of DC power distribution will be researched with a view to include these aspects within any future CoP and Standards. This knowledge will be vital within the rollout phase (Phase 5) of this transition (Section 6.5.8).

According to interviewee 15, small changes to appliances can take a few months and a completely new product can take up to 4 years. Therefore, putting together a prototype house, which requires further bids for funding and adding more expertise to the team. This phase is given a 4-year time period.

6.5.7. Phase 3 public engagement

The question is why is phase 3 public engagement? Is not public engagement throughout the transition process across all the phases as shown in Theme 7 advocacy of a concept? (see Table 6.1 above)

Engaging with people outside the core team about the DC project starts right in the beginning at the scoping stage of team building (see Section 5.7 Theme 3), which besides team building is procuring seed funding (Figure 6.8). Writing academic papers and using the media to publicise the research is also part of public engagement, which is part of Theme 2 and is about informing and influencing public discussion of the subject. However, as a specific phase within the transition timeline this research puts public engagement at the point where mainstream policy makers, the markets and wider industry become engaged. This will be towards the end of the prototyping stage and beyond. This will be the time when the coalition will be trying to get the DC project onto the mainstream agendas of all the different institutions set out in Section 5.7.1 above.

Geels explains that governments are reluctant to pick winners and prefer to leave it to the markets ‘to decide about innovations, including low-carbon options’ (Geels, 2014b). It will be difficult to bring in the policy makers before a demonstration prototype, that can show the advantages of DC over AC, has been implemented. This is why this phase comes after the prototype phase and after some sort of standards have already been drafted.

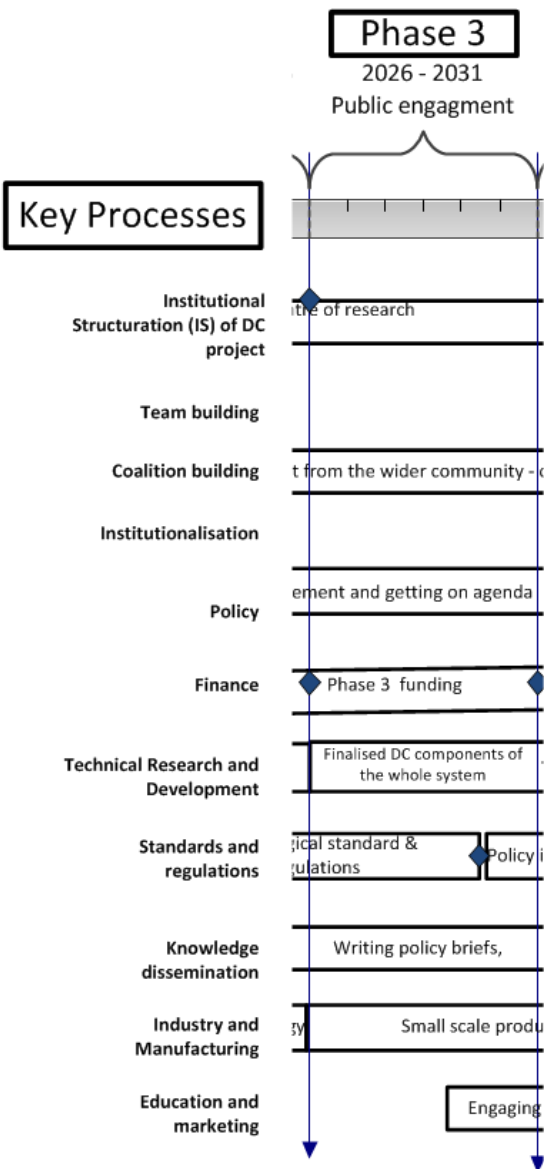


Figure 6.8 Phase 3 of the transition

The methodologies and type of approaches to present information to policy makers is presented in Section 5.10.2 above and includes countering corporate lobbying. In Section 5.11.1, interviewee 12 identified that there are many interns working within government departments who are paid by industry and the corporate world. They act as consultants, or researchers, but are not necessarily there to be lobbyists. However, as interviewee 12 put it, they “*do have influence*”. Therefore, providing a balance or advocacy to overcome any adverse corporate influence is very important within this phase.

The Research Councils (interviewee 2), government departments and the government itself operate within a 5 yearly cycle. Similarly, the UK government’s comprehensive spending review sets out the government’s spending plan for a five-year period, however this review has taken place in 2007, 2010, 2013 and 2015, thus changes were introduced in a shorter time frame. At this stage the higher order Standards (see Section 5.9.1) will have to be developed, therefore a timeline of at least 6 years has been chosen. Public engagement will be ongoing and will exist with different intensity from the beginning of the project. However, this phase will be 6 years of high intensity public engagement, on which the successful furtherance of the project hangs. It is, therefore, fixed as an individual phase of the transition before a pilot project in the public domain can be implemented.

The question is, what is the process for the development of standards, (including Health and Safety) and the policy instruments, (including funding tax breaks etc.), that will enable a pilot project to operate within the community and transition out into the wider world? Two pathways came out of the interviews: either the process for a transition can be driven by the markets first and then policy makers follow up with policy, this is a bottom-up approach, or it is driven by the policy makers with the markets then following, this is a top-down approach. Examples given by interviewee 6 for a top-down approach were the introduction of the GSM and USB standards and by interviewee 14, the higher order standards that are policy driven like the EU’s ‘Construction Product Directive’. Examples given for a bottom-up approach are industrial standards that are market lead these include DC standards for data centres and for the office (EMerge-Alliance, 2013) and VHS video standard (interviewee 4). At this phase of the transition process, the foundation for the DC standards that will be needed should have

already been completed. By ratifying them before a DC market exists, this will catalyse industry and give confidence that DC is a serious technical goal for the electricity system. Producing standards follows a top-down approach, with respect to the market approach which is bottom-up, as the higher order standards and policy instruments are required to be in place before market take-up and nationwide rollout can begin to gain momentum.

### 6.5.8. Phase 4 small scale pilot projects in the community

This phase is Theme 5 and is about how the second stage project, which is a small scale DC development within the community, will develop (Figure 6.9). This is also the H2 stage. To be able to take a prototype DC house into public usage in the form of a small housing estate, will require the ratification of many levels of standards and policy instruments. It will also require funding which could be public or from a national housebuilder. As it is possible that DC could be part of a retrofit, or new-build, 6 years has been given for this stage. A successful deployment will enhance the data gathered and add impetus to the discussion around distributed generation with DC voltage. This will show the housebuilding market the merits of such houses, it will boost exports of technology to developing nations, it will increase the uptake of such technologies by manufacturers and as interviewee 16 said “*As far as industry’s concerned if there is money to be made from it they will do it*”.

All electrical loads should have smart data loggers (RS-Components, 2016) to gather time-of-day and usage duration data, that will be used to identify if

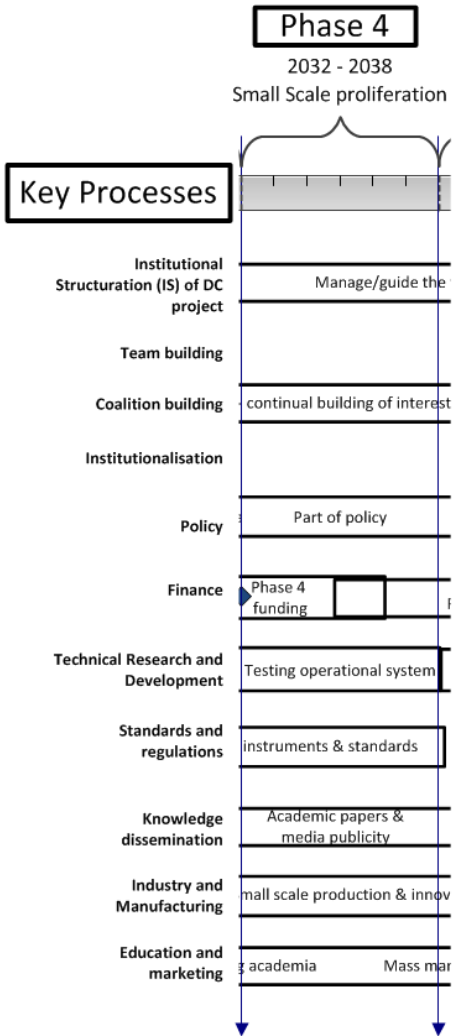


Figure 6.9 Phase 4 of the transition

tasks can be re-scheduled for a more appropriate time of day and to measure peak loads, all in real time. These data loggers should be incorporated into the actual appliance as part of the smart house technology (Smart Home Energy, 2016) which forms part of the Internet-of Things (Lee, 2016). Such data combined with other data for solar (European Commission Joint Research Centre, 2016) or wind maps (RenSMART, 2016) and weather predictions, could be used to make a better specification for different sized houses, in different parts of the country and with different occupational profiles. Measuring user behaviour will also be carried out. This will help to re-shape the DC system to better interface with the users and perhaps be used in predictive modelling for the rollout phase. Within this phase will be the time to update standards, codes of practice and building regulations (see Section 5.9.1 above).

### 6.5.9. Phase 5 nationwide rollout

A national rollout campaign is Theme 6, which is about advancing a solution into the marketplace. Within this phase knowledge transfer, marketing and education is paramount to gaining market share and to the transformation of the electrical regime, this is Theme 7 Section 5.11. Figure 6.10 shows the different processes that will be operational throughout this phase. For further discussion, see Section 5.11 above.

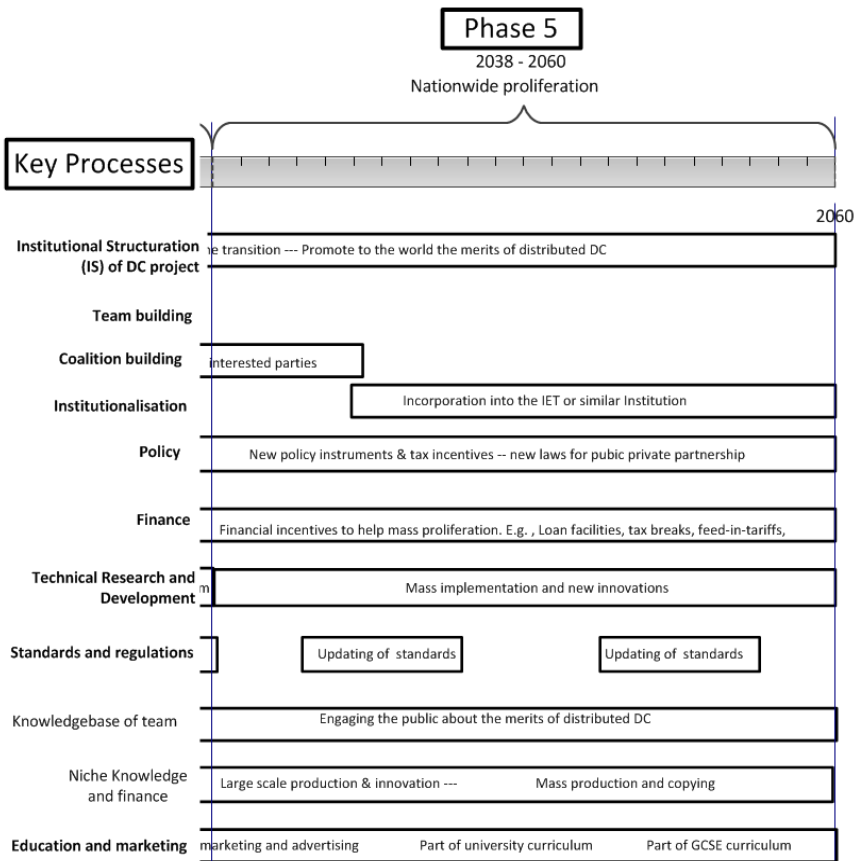


Figure 6.10 Phase 5 of the transition

At what stage the small-scale proliferation will develop into a full scale nationwide proliferation is not known, but it will depend if it is driven by policy from the top-down or via

the market from the bottom upwards. It may be as was with solar feed-in-tariffs, the market followed the policy instruments, gaining pace as the fiscal incentives increased and slowing down as they were withdrawn.

It is also not clear when the coalition ceases. It may develop into a new national body/institution or it may be subsumed into an existing one like the IET. This research has assumed that the coalition as an institution will be involved in the nationwide rollout phase and will therefore stop or change into a new institution, 5 years into the proliferation stage.

A further 23 years has been given for nationwide proliferation, which takes the total projected time for the transition to 43 years, as per Figure 6.5 above. This timeline analysis of the transition provides the key processes that are the enablers for the transition and presumes that they all operate properly according to their proper time and in their proper sequence.

So far the mechanisms that will enable the transition have been discussed and a tentative timeline has been produced that shows the phases and main processes within this proposed transition pathway. However, the questions are: how attainable is this timeline transition? What can the data convey about potential difficulties that are the barriers that could delay the transition, what solutions can be found to overcome these barriers and what can be done to nurture and empower the whole transition?

## **6.6. Turning barriers into enablers for direct current voltage proliferation**

Barriers are influences or pressures that get in the way or hinder progression along the chosen transition pathway. In many cases, the barriers should be perceived as a means to identify the enablers as they are just the other side of the same coin and therefore the solution is easier to identify. However, when it comes to people, sometimes they suffer from lock-in and inertia (see Section 3.2.7), something that is inherent in them and can be a real barrier.

The interview data brought forth some generalised barriers to DC proliferation. The first was people's knowledgebase and therefore attitude to change. The second is the lack of enabling instruments like standards. And third is people's focus on their own expertise without looking



at the larger picture. All the technological barriers highlighted in this research (Section 2.6) are the actual research goals of the conceptual phase of the transition. If the technical aspects of the AC electrical system cannot be re-designed to operate on DC voltage, a transition will be impossible. Therefore, while they are barriers to the transition they are the actual research milestones and not external influences that seek to disrupt the transition process. They are therefore not discussed in this section.

#### **6.6.1. Power of gatekeepers in the transition process**

When a researcher wants to recruit a subject for study or interview, they may have to negotiate with a third party for access. This is especially true when the subject is a child or a vulnerable person (Witham et al., 2015), or if third party information is held by a company (Boddington, 2009). The person/s who holds the ability for access is called a *gatekeeper*. Robson and McCartan (2015) define a gatekeeper as “A *person in a position to give or deny permission for a researcher to gain entry*”. This label is also used for anyone in a position of influence that can veto or stand in the way of a decision. For the transition to take place there is a need to get people of influence on-board, so that they can be enablers. The interviews highlighted instances where gatekeepers can be barriers and it will be up to the coalition who will be guiding this transition, through dialogue and knowledge transfer, to transform these barriers into enablers.

##### **(1) An example within the education system**

Tomorrow's engineers are today's undergraduates. Therefore, the mind-set of those setting the curriculum and guiding research agendas will be important for any future transition. But what if they are locked-in to the way things are done and refuse to engage with idea of using DC voltage? They are not only the gatekeepers of their courses and research agendas but they also may control structuration of their institution. Similarly, if they happen to be part of the peer review process for a funding body or are academic journal reviewers, they are in the position to hamper any transition. One of the interviewees is a Professor of Electrical Engineering who is involved with undergraduates, postgraduates and research. (His expertise is in centralised high voltage DC systems (600 to 800 KV) and not in extra low voltage DC systems (up to 120 V), and therefore this extract does not invalidate the positive comments

from those engineers who have actually implemented DC systems). This academic is in a position to influence the direction of the curriculum, yet seems not willing to be open-minded enough to consider distributed DC electricity systems. Below is an extract from the interview:

1. *Q: Do you think that there is enough knowledge out there for engineers to be able to deal with DC as low power voltage in the home? A: No that wasn't the question you asked, but the answer is no, because it's not commercially important, so we shouldn't waste the time of the students on it.*
2. *Q: So are you saying that only things that are pertinent to implementation today are things that should go into the curriculum? A: No*
3. *Q: So what do you mean by something which is not commercially important? A: Well, you have a certain amount of time and you make a judgement as to what is important and at the moment this idea is not important.*
4. *Q: However, for the point of view of technology i.e. battery-powered cars, battery powered houses it is something that looks like it's going to be in the future important? A: So it can compete with all the other things that might be important in the future and placed in the curriculum, fine.*

This perspective of education and how it relates to the dissemination of knowledge about DC voltage systems, indicates that the institutional structuration of the higher education system may act as a barrier to DC transition. The gatekeepers use what Geels (2014b, p. 28) calls “instrumental” forms of power to perpetuate the status quo, thus locking-out new ideas.

## (2) An example within industrial relations

In Section 3.2.7 above, different types of lock-in are discussed, some of which are technical and some are human. People can be the catalysts as well as the strongest barriers to change. When the owners of the docks in Rotterdam in 1907 wanted to change the process of unloading grain from ships, from manhandling sacks using stevedores, to using huge mechanical cranes, it was the workers' representatives that tried to stop it (Van Driel and Schot, 2005). Negotiating the institutional structuration of the system in place took from 1907 to about 1913 for the final mechanisation at Rotterdam port. The strong union negotiators represented the ‘gatekeepers’.

(3) An example within a Standards committee

When Latimer (2007) describes in detail the process whereby the UK adopted the use of the flat pin plug and the topology of the electricity main as being a ring-main, he showed how the whole process was hampered by the different authorities and powers that existed within the group of institutions that were involved in the decision making process. These quotes from Latimer's Section 7.9 and 7.10, illustrates the complex interactions and conflicts between the many personalities, Institutions, committees, sub committees and previous published official government documentation, when they were trying to develop the new standard for the plug:

*"... that the **Codes of Practice Committee** should be the body to reach the final decision and that **Electrical Accessories Section of BEAMA** had agreed to abide by this decision. **The Chairman of the Appliances Sub-Committee** confirmed that this correctly expressed his recollections of discussions but **Mr Watlington** of BEAMA was unable to concur. **Forbes Jackson** considered that the broad principles should be addressed and that the **EISC** who had been unanimous in recommending the publication of a supplementary report was fully representative. They had been supported by a large proportion of **the supply industry** and also by the **Electrical Industry Committee of BSI**. Furthermore, the new all-purpose standard socket outlet had been endorsed in the **Housing Manual 1944**. He proposed the Codes of Practice Committee should accept the EISC's proposal.*

*However, **Mr Jones** of the **Electric Lamp Manufacturers Association**, said that while the supplementary report of the EISC said that their conclusions were unanimous, his support had been contingent of the use of the standard all-purpose plug being made mandatory. The Committee learned that the Electrical Industry Committee of BSI were prepared to re-discuss the matter in the light of any new findings by the COP Committee. It was noted that the Post-War **Building Studies No 11** was not necessarily binding on the Code of Practice Committee and acknowledged that their findings should be regarded at the starting point for any further discussions..."*

This type of interaction between many diverse institutions had been going on for years. This shows how important negotiating institutional structuration is to the transition of a new technology. It needs not only to negotiate the different institutional structurations of individual institutions, but when many institutions have to reach agreement for a transition to take place, the interactive institutional structuration of many institutions will also have to be negotiated. Therefore, institutional structuration while being the enabling force to make change, is itself the source of many of the barriers to change. Navigating through the

institutional structuration of the standards committee took many years until the BS 1363 was ratified in 1947.

These examples show how people act as barriers to change. However as explained above in Section 5.10.1, many of the interviewees had extended influence beyond their normal work: as members of committees, as consultants, as part of consortia and as active members of professional associations. These people therefore act to bridge the gap between many different institutions and act like '*boundary spanners*' as described in Section 5.10.1 above. This therefore makes them very good enablers for the transition.

Therefore, the first hurdle to any transition, including a complicated market transformation like this research, is to negotiate the rules, methodologies, mind-set and practices of the gatekeepers within all the institutions that will be affected by this transition.

#### **6.6.2. People's preconceptions and education**

All of the interviewees are experienced people who work in senior positions within their organisations and all work within the energy, sustainability and climate change fraternity, see Table 5.2. Before the interviews took place this research identified electricity as being under represented within the disaster and resilience literature (Kinn and Abbott, 2014). Therefore, there was an expectation that those interviewees who were not electrical engineers were no different from those in the disaster and resilience fraternity and may know little about the connection of electricity to their fields of work. However, how unresponsive to DC electricity they were and the manner of their response when electricity was mentioned, only came out through the interview process.

Initially, when prominent academics and heads of think tanks, national bodies and appliance manufacturers were approached, the title of this research which is about electricity was mentioned as a key component of the interview. The content of their e-mail and telephone responses included that electricity was not their subject and they therefore, felt that they were not the right people to be interviewed. It was realised that what people would be happy to talk about was their work and the way their institution handled change, this was the institutional structuration information so important to this research. However, regarding the non-electrical

engineers who did accept to do an interview, their response to questions about electricity reinforced the work carried out on the disaster and resilience literature, that electricity is not within the focus of many in the sustainability and climate change fraternity. Many worked in institutions that had no electrical engineers. This is a major barrier to the proliferation of DC electricity systems, as such systems could be used to alleviate the global challenges that many of the interviewees are working on, yet these very influential people felt it was a subject for the engineers and not for them. Similarly, the engineers when asked questions about carbon footprint, how electricity could enhance energy security and energy independence, or how engineering solutions could affect energy policy, did not fully engage with the line of questioning. While this research has highlighted the division between the social scientists and the engineers it is appreciated that three of the interviewees were engineers that engaged with social ideas. However, generally this ideological division was found to exist between the social scientists and the engineers interviewed. This is in fact an example where there is a lack of people who are able to bridge this gap and act as boundary spanners (Williams, 2010).

Unfortunately, some of the electrical engineers were also not ready to entertain the notion that distributed DC electricity could have its merits. Some of the interviewees had some preconceived notions about distributed energy generation against centralised generation and DC voltage against AC voltage. Some of them were so entrenched in their ideas that they were either not willing to engage or were dismissive. Some of the ideas that formed part of the Edison and Westinghouse debate over 130 years ago (McNichol, 2006), still today resonate with some people. As interviewee 12 put it; “... *there are lots of myths around it (dc) so that may be a big barrier...*”.

Below are some examples of how some of the engineers reacted to distributed electricity and DC systems:

(1) Scalability within engineering solutions can allow a multifunctional larger system to be scaled down for use within a more limited environment. For example transformer technology can be used to step down voltage from hundreds of thousands of volts to tens of thousands of volts, at the same time a small transformer can step down the voltage from 230V to 12 V, this means that transformers are scalable, even if the internal technology is vastly

different. Therefore, in order not to re-invent the wheel the following question was put to interviewee 14 who is an electrical engineer with over 30 years' experience:

Question: *"Do you know if the current building management systems are able to be used in the home to manage a DC mains system?"* Answer: *"You don't need them domestically, so it is an irrelevant question."*

There are emerging technologies for consumer home energy management, such as Nest Lab's home automation technology (Nest, 2016) and British Gas's hive technology. (Hive, 2016). While these are not full 'building management systems', they are data loggers and management systems for a specific aspect of home energy management and therefore could for part of a full domestic energy management system. This means that domestic management systems that are in use, albeit only in a limited way, may be more relevant for a future smart DC house, than for retrofitting into the present AC home.

(2) One way for DC to proliferate is as part of the retrofit cycle. According to interviewee 12, on average, a house is re-wired every 30 years while for commercial buildings it is every 5 to 7 years. For this reason, interviewee 4 stated that the focus for DC at this time - in 2016 - is on the office environment. When this was put to interviewee 14 his response was as follows:

*"Do you know that for our building stock only one half percent change per year and only 1% is renovated, that means it will take a hundred years to upgrade the building stock."*

And interviewee 4 responded "... 80% of the housing stock (that will be available in 2050) is already built..." "...we have tended to look at that (DC) from a large commercial perspective rather than doing it at the domestic level."

These responses take no consideration of a top-down planned transition like that which took place for town gas to natural gas (Williams, 1981), but indicate that they are only looking at transitions that rely on the 'people power' like the proliferation of rooftop PVs or market driven transitions, which can take a very long time. Therefore, both of these interviewees see domestic DC as unviable, as it will take too long for proliferation. Two people very influential in the preparation of the IET's code of practice for DC, who have steered the direction of the

IET's DC goal towards the office environment, have quoted this 80% comment above, as a crucial reason not to focus on domestic application for DC voltage. However, while percentages are statistically significant how many new-build houses are to be built in real terms by 2050? What is the projected number of houses that will be retrofitted by 2050? Also is their combined total high enough to significantly affect the ability for DC systems to proliferate into the built environment?

The average amount of new dwellings built per year in the whole UK for the ten years from 2005 to 2014, was 169,454 (Department for Communities and Local Government, 2016). If a best-case scenario was that all of these had a DC electricity system, over the 23 years given for the proliferation phase, this would be 3,897,442 new dwellings. If 169,454 represents the 0.5% stated by interviewee 14 above, then the 1% for renovations quoted to a total of 7,794,884. This will give a total of 11,692,326 potential DC houses within 23 years, which is approximately a third of the projected number of households for 2050 of approximate 31.81 million (Boardman, 2007, Table 1.4). On page 36 of the 2007 report, it states that the UK government wanted to build 10 new eco-towns in the UK, each with 5-20,000 homes. A town of 20,000 is also projected for an off-grid Australian town (Williams, 2016). Therefore, there is the potential in the UK for whole new towns that may be built before 2050 to be built using distributed DC electricity systems. In theory at one new 20,000 unit town per year, that would create 23 new DC off grid towns with a total of 460,000 new homes before 2050. However, if the snowballing effect that fiscal incentives and mass market proliferation cause takes hold, potentially all the ten million new-build homes that will be built by 2050 (Boardman, 2004, Table 5.1) could incorporate DC. This number increases to 17 million if retrofitted homes are included and shows the potential for an increase in the UK's energy independence with security, which could add to national security.

While these statistics are 'projections' and 'scenario' based, this research sees new-build as an enormous potential opportunity into which DC electricity systems can be installed over the next few decades. It is appreciated that to date (2016), new-build has not really kept up near to the projected 240,000 per year, however the potential within new-build and retrofit is real and could be an opportunity for distributed DC.

Although electrical plugs and sockets are less complicated than changing from AC to DC it took only 20 years between 1948 and 1968 for the flat pin 13 Ampere plug to replace the round pin plug system that had been in place since the early 1920s (Latimer, 2007). It took a further 20 years for the round pin plug to disappear from the home. The same is potentially possible that DC could proliferate over a 40 a year period. However, it is possible that the correlation between the transition between round pin plugs and flat pin plugs, to the transition from AC to DC is not correct. The transition to the flat pin plug enjoyed a helping hand as there was a huge wave of post war new-build, according to Latimer (2007) *“one million houses were going to be built immediately after the war”*, while the new-build to 2050 will be over a much extended timeframe of more than 30 years.

(3) This research found that some of the interviewees were only looking at domestic DC as a straight replacement for AC and therefore could not see DC as any use for the higher-powered domestic appliances. These include: a kettle, cooker, washing machine, dryer, dishwasher and microwave oven. However, there are already DC air conditioners (Airva, 2016) and fridges and freezers (Green Energy Inovations, 2016), as well as entertainment, personal, kitchen and security technology (RoadPro, 2016). A question that was asked to one of the interviewees: *“What would you say needs to be in place in order to have the other loads, for example white goods and high powered goods DC appliances?”* Answer: *“I don’t think those appropriate for DC.”* When it was mentioned that DC systems could be used to replace wood that is used on a daily basis by millions of people worldwide, it was acknowledged that for such a scenario there was a use for DC.

(4) Some of the Health and Safety laws are to safeguard people from electrical hazards. Engineers know that hazards can be technically challenging but should not be used as a reason to reject a technology out of hand. Interviewee 10 explained that DC is dangerous because *“...the amount of current is quite high therefore that tends to push up voltage which increases fire risk.”* To deal with this problem this research envisions the re-engineering of all domestic appliances to operate at their optimum voltage and to have at least two voltage values within the home, one for low powered and one for higher powered appliances, each having its own set of wires and plugs. This is no different from the historical domestic mains system as explained by Latimer (2007). In many houses today there are already three separate sets of



mains wires: (1) rated 5 Amperes for the lighting ring main, (2) a 13 Ampere ring main for the plugged in appliances and (3) a 30 Ampere main for higher powered appliances such as some electric cooking ranges or high powered air conditioning units, which are directly wired into a fused wall socket.

(5) With regard to introducing DC systems for domestic consumption into the education system there were two opposite reactions. The positive reaction came from an engineer who himself stated that the biggest antagonists to his work of trying to promote DC standards for commercial buildings were electrical engineers. The negative reaction came from a professor of electrical engineering who specialised in smart grids and high voltage direct current (HVDC). Below is the positive comments given by interviewee 4 about DC education.

*Question: Do you think it would be difficult to get modules in electrical engineering courses about DC? Answer: No I don't think it will be very difficult. I think you will need to find some more enlightened technologist of the type like Miles Redford is and work with them and I think what will happen as a consequence of that is as you get people going through that program and coming out of the other end as graduates and going into business, they start to create an influence. This being a long term project it is a long term as the first project was in the first instance." i.e., the Edison verses Westinghouse and the DC to AC transition.*

(6) During interview 12, the concept of the vulnerability of the national grid to cyber or terrorist attack arose. The incident in the 1970s where IRA terrorists allegedly planned to destroy the grid to London (Nye, 2013), was used as a reason to show the vulnerability of the centralised system. Interviewee 12 stated that *'I don't think that you can say the national grid type system is actually that vulnerable, actually historically it has worked very well that is why there is not the kind of big political drive'*. In other words as the UK has not suffered mass power cuts, like for example in the USA (Balducci et al., 2002), there is nothing to be gained in using possible vulnerabilities of the centralised system as a reason to transition to a distributed system. Such thoughts are seen as short sighted and a barrier to the transition to distributed DC electricity. In late 2015 Crimea suffered a large spread blackout due to the destruction of some pylons bringing electricity from Ukraine (BBC News, 2015). The Russians claimed that they were deliberately blown up by the Ukrainians and the Ukrainians

claimed it was high winds. A good energy policy would not wait for disaster to strike but would build in resilience, that provides energy security.

The knowledge base about distributed DC systems for consumption purposes is in what Schmidt calls the “*immature stage*” of his 5 stage Knowledge Maturing Process (Schmidt, 2005). His 5 stages are: (1) *Emergence of ideas*, (2) *Community Formation*, (3) *Formalization*: includes project reports, (4) *Ad hoc training*: includes best practice and (5) *Courses*: includes Standard text books. This perhaps is a reason for these reactions from the interviewees, their knowledgebase about DC is at Schmidt’s “*immature stage*”. Therefore, for DC to transition successfully the knowledge about DC will have to go through these maturing stages, something which will take time.

Another possibility is that these interviewees, who are experts in their particular field see DC as ‘outsider knowledge’ (Devaughn et al., n.d.). Dolby (2002) sees, “...*the specialist is an outsider to all of science except his own specialisation. It is not insider knowledge but outsider knowledge which is the predominant shared resource of the scientific community as a whole.*” Therefore, since the use of distributed DC systems for off-grid homes that include DC internal mains wiring and DC appliances, is a relatively new subject, then even the electrical engineers may be seeing DC as an “outsider subject” which perhaps is intruding into their AC world. This lack of understanding and technological awareness about the basic electricity system and loads was seen by the interviewees who are engineers as a major barrier for a transition to DC (see Section 5.5.1).

Some suggestions from the interviewees for knowledge transfer were: write blogs, use social media like Avaz and 38 Degrees, write policy briefs, lobby MPs and their assistants, lobby Parliamentary select committees, make presentations and connect to like-minded people thus building a coalition/community. A surprising number of interviewees pointed out that with respect to academic literature, while it may be picked up by some in industry, policy makers do not have the time to do in-depth literature reviews and therefore it is largely “*ignored*”. It was also pointed out that the language of knowledge transfer is very important. There is a problem that the written word becomes too technically specific to the discipline of the academic. Thus the language of a social science paper written for a fellow social science

academic, or a technical paper written for other engineers, builds a semantic barrier between the two fraternities as it is like two people speaking different languages. There is also the knowledge gap between what the sustainability and social scientists need to understand about how electricity affects their problems, like the UN's 17 sustainability goals and the engineers who understand very little about how their skills could be used to alleviate these sustainability issues. The solution is that with more knowledge transfer within the whole education system and more people writing papers with a wider audience in mind, this gap can be bridged. As interviewee 3 put it: *"we are not at this stage on the road or on the journey to adopting DC, we are at the point where we are having to educate people that DC is actually an option available for their consideration."*

When a new government report comes out it is always interesting to see how prominent electricity is within these documents, therefore a word search for 'electricity' is made. What was found was that electricity is a very obvious problem with which people do engage with. While nothing operates without electricity, the subject is absent from many documents. In the 123 page report from the House of Lords Select Committee on National Policy for the Built Environment, entitled, 'Building better Places' electricity is not mentioned once (House of Lords Select Committee on National Policy for the Built Environment, 2016).

Some of the barriers and enablers that arise from people's ways of thinking are shown in Figure 6.11 and some of the technical barriers and enablers are shown in figure 6.12

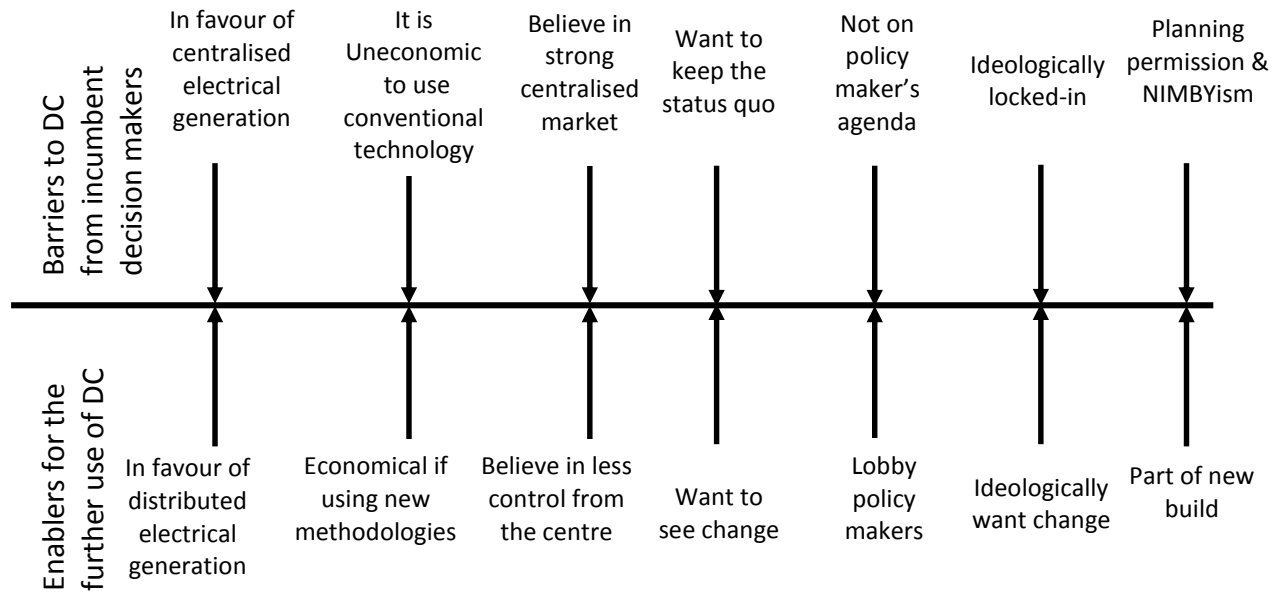


Figure 6.11 Some of the social barriers and enablers.

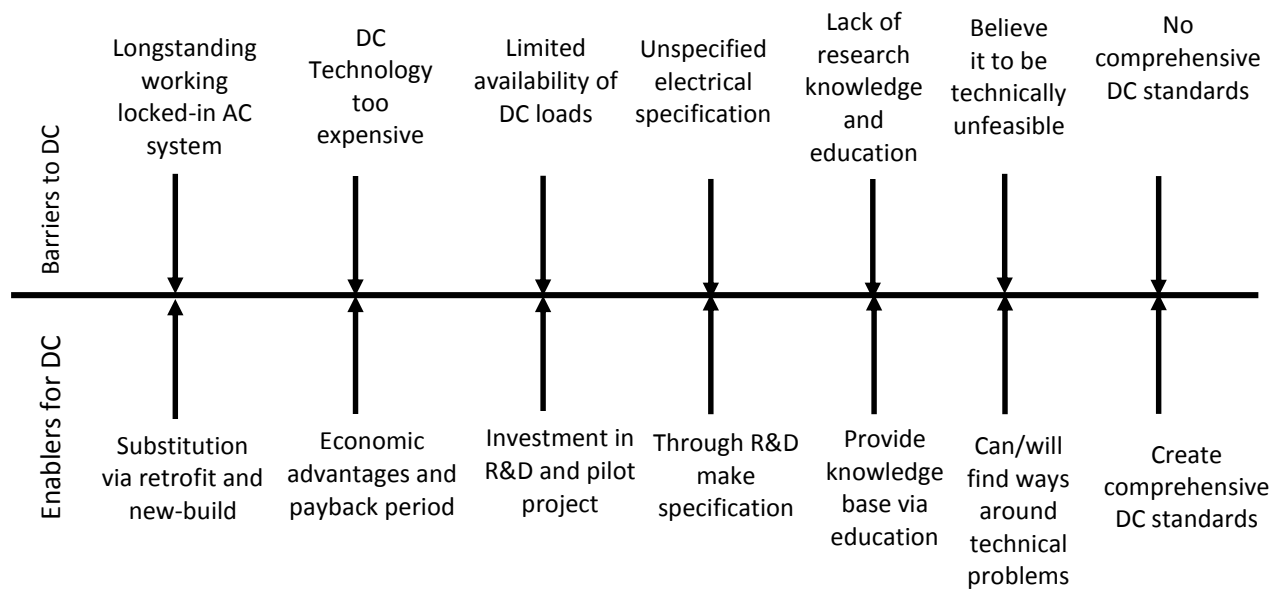


Figure 6.12 Some of the technological barriers and enablers.

## 6.7. Is the transition to DC voltage an insurmountable wicked problem?

The transition framework, with its five phases and 43-year timeframe is described as an idealised transition pathway. As explained this is because much of the research is yet to be done and therefore only as the research progresses will the transition pathway develop into a more tangible reality. This research has highlighted many barriers and enablers, many of which need the alignment of many diverse actors to come together in order for the transition to succeed. This transition is a national market transformation programme that has a long timeframe and the need for the alignment of many factors that traditionally are siloed. It is a cross disciplinary project that will require the cooperation of people in many diverse academic fields including bridging the gaps between social science and engineering ways of thinking. Further to this is the mismatch between energy policy in the UK and the way it has been implemented, as has been highlighted by ‘The Conundrum’. The main challenges will be “... *to overcome the rigidities and path-dependencies of already existing, highly institutionalized system structures and to build up new, more sustainable ones*” (Fuenfschilling and Truffer, 2014). Due to all these factors it has been suggested that this research project is an insurmountable **wicked problem**, first discussed by Horts Rittel in the 1960s.

Rick (2015) summarises wicked problems with the following seven points:

1. *are intractable and difficult to define;*
2. *are multi-causal and possess complex interdependencies;*
3. *generate conflicting stakeholder perspectives that may be driven by strong ethical, moral, political and social dimensions;*
4. *sit astride ecological, society, enterprise and other boundaries;*
5. *are associated with chronic policy failure;*
6. *demand complex judgment in the face of urgent, high-stakes resolution when no clear solutions are available; and*
7. *“Solutions” yield unforeseen challenges that are neither right nor wrong, only better, worse or “good enough”, thus implemented solution alters the challenge.*

Any solution provided today will not solve the total problem but will lead to ripple effects some of which may be today undetermined (Davison et al., 2015; Edgeman, 2015; Turnpenny et al., 2009). As Churchman (1967) puts it, “...*proposed “solutions” often turn out to be worse than the symptoms*”. These undetermined affects may turn out to be undesirable but are now locked-in due to yesterday’s decision. Wicked problems by definition are complicated and

find themselves difficult to become resolved, because “*one has to develop an exhaustive inventory of all conceivable solutions ahead of time*” (Rittel and Webber, 1973).

Edgeman articulates numerous wicked problems that are connected to what he calls wicked sustainability challenges, 12 of which are:

1. *habitat and ecosystem services losses (Pejchar and Mooney, 2009);*
2. *biodiversity loss (Sharman and Mlambo, 2012);*
3. *soil erosion, degradation and contamination (Gnacadjia, 2013);*
4. *photosynthetic capacity limitations (LePoire, 2014);*
5. *alien and invasive species introductions (Pejchar and Mooney, 2009);*
6. *freshwater limits (Bakker, 2012);*
7. *overfishing (Khan and Neis, 2010);*
8. *energy limitations (Koomey, 2012);*
9. *human consumption levels (Moser et al., 2012);*
10. *toxic chemicals (Allen, 2013);*
11. *population growth (Head, 2008): and*
12. *climate change (Koomey, 2012).*

In fact Turnpenny et.al.(2009) point out that the UK’s energy and climate change policy is a wicked problem. So is the transition to DC voltage an insurmountable wicked problem? Is it something fundamental about the approach to solutions that have led to the conclusions that wicked problems cannot be totally solved?

One person has shown that by using a ‘design’ approach (Roberts, 2012), what looks to the world as a wicked problem has been tackled with great success. Willie Smits, through his various projects over the last 30 years in Indonesia has managed to provide solutions to the following wicked problem. Borneo had suffered for many years with deforestation. The shrinking habitat led to species and plant extinction. According to Roberts by 2005 following bouts of huge fires “*Borneo lost a swathe of forest the size of Florida*” which is about 170,000 Km<sup>2</sup>. Besides health problems caused by the fires, unemployment went up to 50%, crime rates went up and people were spending a quarter of their income on drinking water. This combination led to people hunting orangutans for food and trading. When Willie Smits came to Borneo in 1991, what he saw was the need to save the orangutan. The problem was that their habitat was constantly shrinking, at two million hectares per year, which was taking around 3000 orangutans. The local population had many social problems and saw orangutans as a resource. The authorities had, through their policy of draining the swamp, exacerbated the

problem and corruption was rife. So how does one save the orangutans without a forest to put them back into and without help from the population? These are the details through which Roberts sets out to show how this was a wicked problem.

The solution was to start small taking a step at a time. First with an orangutan sanctuary, then plant a newly seeded small forest from scratch, then to purchase land on which to resettle people who could make a livelihood from tapping sugar palms. This provided habitat for wildlife and income for people, who crossed over from being hunters to becoming ‘forest rangers’. Then together with the local geothermal plant providing the energy needed to process the palm sap into sugar and ethanol, this part of the project saved up to 200,000 trees a year (Roberts, 2012). Over the last 30 years the program that started off as animal conservation, has had successful reforestation and wildlife reintroduction projects, has provided sustainable production methods and grown the local economy. The success according to Roberts has been because the problem was: (1) tackled from the “*bottom up using design*” methodologies, (2) “*start small and thinking with your hands*” – this is about operating at a manageable scale, (3) created the environment whereby problems secondary to the initial goal were solved - the project to protect endangered species ended up providing economic growth, that reduced unemployment and crime and corruption and (4) the project built community consensus, the “*design became ‘creating with people’*”, that is it took the people along with it.

There are many parallels between the approach and methodology that Willie Smits used in his solution and that advocated by this research. The time scales of both projects are in the decades, this solution also uses a bottom up approach and together with coalition building this research methodology is to start small scale to build confidence in DC systems and then slowly grow the user-base towards nationwide proliferation. The primary goal of this project is to attain energy independence and energy security, with all the other UN sustainability goals being alleviated as second order results. This research is doing what Geels (2014b, p. 30) refers to as “*the diagnostic framing*” of the problem, i.e. it is changing the emphasis of what the goal should be for the UK’s energy policy away from the trilemma, to a policy where energy independence with security is central. However, it is not being done to deflect the goals of the trilemma, thus undermining them, as Geels suggests in his paper, but rather to

create an environment where they will be secondary consequences of the policy, rather than the main focus of the policy and be a detriment to energy independence with security. Therefore, this research concludes that while a nationwide market transformation program to change the electricity system to a distributed DC system ticks all the boxes of an unattainable wicked problem, by using bottom-up design methods the transition has a good possibility of being attainable.

## **6.8. In conclusion**

This research has used a layered approach to produce the timeline transition pathway shown in Figure 6.5 above. Its underlying theory is the MLP on sociotechnical transitions, it used multi-method case study to gather data, then thematic analysis and the '5W plus H' approach, to analyse and sequence the data and it then used the phases and timeline, based on the interview data to depict a tentative transition pathway.

Some conclusions arising from the interview data:

1. One has to question whether there is a skew in the knowledgebase of energy and sustainability experts. Their lack of interaction with the engineering side of the sustainability and policy debate is seen as a huge knowledge gap by this research and because they are in positions of influence, a barrier to a transition to DC.
2. This lack of understanding and technological awareness about the basic DC electricity system and loads was also seen by the engineers as a major barrier for a transition to DC.
3. Also many of the interviewees either knew nothing or very little about the association of energy security and energy independence with decentralised electricity systems which besides being a present barrier, is an area for further research.
4. For professionals to take up a transition to DC they will need to understand and appreciate the whole sociotechnical picture of the energy and electricity system.
5. While this transition may have all the characteristics of a wicked problem, the bottom up design approach used by this research provides a possible pathway for the transition to be successful.



# Chapter 7

## Conclusions and further work

### 7.1. Introduction

The objectives of this research were to identify the components that would enable a transition from an electrical system that is a centralised AC voltage to one where distributed DC voltage systems proliferate (Section 1.2). While characterising the UK's electricity system it became apparent that although technical, it has many social aspects, which leads to best describe the electricity system as sociotechnical (Section 1.3.1). Framing the research is very important, this led to choosing the multilevel perspective (MLP) on sociotechnical transitions (See Section 3.1) as the theoretical framework for this transition. This research has three threads that run through it. The first is the sociotechnical nature of the electricity system and the interactions between electricity and societal problems, such as how distributed electricity systems can be used to enhance city resilience (Section 2.4). The second is the development of a transition framework that shows the stages and components of the transition. The third strand is the unique use of the MLP theory as a tool for a future transition and includes a critical reflection on the theory. By identifying the many social networks in the sociotechnical electrical regime (Section 3.2.8), and by using institutional theory and structuration theory (Section 3.2.6), a broader and more detailed understanding of the electrical regime has been reached (Section 3.5.1). The concept of landscape within the MLP has been reconsidered, perhaps allowing a different consideration of this concept (Section 3.5.3).

Researching the transition to DC voltage systems has identified some interesting implications for technical transitioning. These are: technical innovations (Section 5.5), knowledge transfer (Section 5.5.1), ownership of transitions within the energy field (Section 5.7), and complexity and the direction of approach to the transition problem. While the MLP has been used for a number of years as a leading theoretical framework to understand historical transitions (Section 3.1), in its present form it may be considered more limited as a tool for understanding a future transition. However, through an analysis of the regime and landscape (Section 3.5) this research tentatively shows that the MLP can be used to encapsulate a complex interconnected multi-system problem (Section 7.4.6). This research has sought to fill

the gaps identified in the literature review, thus adding to the knowledge base of sociotechnical transitioning. However, this research should be viewed as a ‘thought experiment’; it looks at a future theoretical transition and is thus constrained by some limitations (Section 7.6). New avenues for further work that have developed out of this research are explored (Section 7.7).

## **7.2. Summary and key findings**

The main research question (see Section 1.2) was: if the UK is to move to an electrical system that includes the many advantages that direct current voltage systems can provide, how would the transition be accomplished?

The first aim for this research was to establish the sociotechnical nature of the distributed DC voltage system. Initially, it was thought that the electricity system was mainly technical but surrounded by some less purely technical concepts, for example standards and research. When the concept of transition comes into play, then other concepts, for example energy policy, energy markets and finance, start to emerge as important connected fields of interest. With the choosing of the MLP theory and delving into the electricity system through the eyes of the theory, it was found that the social aspects of the system were in fact on a larger-scale than the technical aspect. To facilitate the understanding of how the transition can occur, one technical and seven social networks that make up the sociotechnical electrical regime were identified (Figure 3.6). However, even this was acknowledged as only being a partial picture.

The question emerged, how do these networks operate within themselves? As nothing operates within a vacuum, it was important to identify boundary points between the different social networks. To identify these boundary points, the components within the networks had to be identified. These components were labelled ‘institutions’ according to the widest meaning of the word (Section 3.2.6). This means that organisations, committees, or types of primary fuels are all labelled as institutions. The label ‘institution’ is a conceptual construct and does not necessarily have to be a physical thing like a business organisation. A good example of the usage of the label institution is in the ‘institution of marriage’.

All institutions have specific ways of operating. These are the rules, regulations, understandings or norms that actors within these organisations are bounded by and use in the daily operation of the institution. The processes involved in making decisions, which are about taking actions within and on behalf of the institution, have been labelled institutional structuration. The institutional structuration identifies the boundary points where interactions take place between different social networks within the sociotechnical electricity system. The boundary spanners are the agents within the institutions that enact the inter-institutional structuration.

Establishing that the electricity system is sociotechnical, was not only about identifying that there are other aspects besides the technology of its physical system, it was about what these other connected concepts were. Still this was not enough to establish pathways for a transition. Boundary points between the networks, what or who were the boundary spanners and what mechanisms they use to bridge these boundaries were identified. What the characterisation of the social aspects of the electricity system established was the content of the sociotechnical framework of the electricity system, i.e. a generalised set of networks with some of the institutions (Figure 3.6). The next stage of this research was to identify the details of the structuration, the boundary points and the boundary spanners. This was carried out via collecting primary data through semi-structured interviews. This represents the ‘what’ will be transitioning part of this research.

The question now arises; given that every country in the world has some sort of working centralised electricity system, why would this research seek to replace it with a direct current distributed system?

The next issue is therefore context. This is about the reasons surrounding the decision to transition to a new electricity system from one that is still in good working order. The GEA (2012) identified several Global Energy Challenges, which it connected to the energy system (Section 1.3.1), and stated that 21<sup>st</sup> century energy systems are not able to deal with these challenges (Section 1.3.2). Further to this, the UN’s 17 sustainability goals for 2030 (Figure 6.1) and the EU’s 2020 Horizon goals were identified by this research as being potentially alleviated with the use of distributed DC voltage systems. This was the context into which the transition to DC was to fit. Not all these challenges are directly pertinent to the UK, however

city resilience and liveability are. Therefore this research looked at the functionality of the built environment in times of power cuts (see Section 2.4), which in itself supplies the advantages and disadvantages of the centralised topology of the electricity system with a distributed topology. It was found that the loss of electricity not only affects the functionality of critical infrastructures within the built environment, but also affects the people's liveability and daily living standards (Section 2.3). This led to connecting electricity to disaster risk reduction and the management of post-disaster reconstruction. This analysis parallels the need to increase a city's resilience against all kinds of disruptions and that an important part of the UK's energy policy should be focused on energy security with energy independence. These discussions represent the 'why' part of this research.

The second aim was to identify a transition pathway (Section 1.2). Since a transition implies a change, the question for this research was 'what form would the change take?' Theory suggests five possible pathways, four singular and one hybrid (see Section 6.2). Developing the transition framework was the 'how' part of this research. Twenty interviews were carried out to gather primary data about the details that would be involved in the transactions (Section 5.2). The theory and published data suggested that institutional structuration would be an important aspect of the transition and would incorporate many of the barriers and enablers. This was therefore a major theme throughout the interviews.

In the first part of the data analysis, thematic analysis was used to develop themes, within which key processes for the transition were identified. Some of the key processes are pertinent to a particular phase while others thread through the whole transition. From the interview data, a product development pathway was identified as a robust framework for the transition. Added to this, the '5Ws plus H' analysis was used to sequence the transition processes into 5 phases. By mapping the key processes and phases within a timeline graph, a transition pathway was established (Section 6.5).

A main driver for the transition to DC systems was seen by some of the interviewees as being the market, which is driven by its motivation to make profit. However, for this to happen there are many prerequisites, these include: robust underlying research, ratified standards, long-term governmental support including fiscal and regulatory policy, and technology champions to oversee and guide the transition. A main barrier to this transition was seen as a

lack of knowledge about what distributed electricity systems can offer, the underlying modern problems of a centralised system, and the advantages of DC systems. This enabler and barrier can be dealt with by increasing people's knowledge about DC systems, which should start at school level, and continue into post-doctoral research (see Section 5.5.1).

Just as energy transitions do not happen in isolation, so to the transition from a centralised AC electrical system to one where distributed DC voltage proliferates will require the coordinated efforts of all the actors in the social networks. It will require a robust public policy framework and an adequate institutional infrastructure to help make things happen. Through the use of the many policy instruments at its disposal, the Government provides confidence to the markets. Just like there is a need for major policy and institutional reforms for many of the energy transitions advocated by the GEA to make a successful transition, so too will the transition to DC electrical systems. It is concluded that the underlying power for this transition to be taken up by the market is the Government.

There was some concern by some of the interviewees that the specification for the future DC systems could suffer 'capture by the market' and could lead to 'stranded assets' (Section 5.5.2). It is possible that if this happens, such as with the QWERTY keyboard, DC technology could end up being suboptimal technology (Section 3.2.7). To guarantee that any future technology does not suffer these disadvantages, it was suggested that the initial research to optimise AC technology for DC voltage, should be independent of the market. It should be carried out within a university and under academic auspices. A consequence of this is that independent academics should therefore form part of the core team and coalition that will be guiding this transition (Section 5.7).

Market transformations and sustainable transitions can take a long time to happen. From the transition literature (see Section 6.5.1) and from researching the transition from round pin plugs to flat pin plugs, it is concluded that 50 years is a reasonable time period for the transition to DC (Section 5.12.5). It is possible that it may take longer, if it is compared to the transition to a sustainable energy system, which is still in the process of decarbonising since the process was begun in 1972 (see Section 3.5.4).

The consensus of those interviewees who advocated the use of DC voltage for the home was that the best system should be a hybrid grid connected AC and renewables DC system, and that there should be at least two voltage levels, one for low powered and one for high powered appliances (Section 5.5.3).

While this research may seek complete off-grid autonomous DC voltage houses in order to fulfil the goal of energy security with energy independence, in reality, in the UK where there is a working mature AC system, DC can or will have to operate in conjunction with AC as a hybrid system (see Section 5.5.2). This research has not concluded what the best scenario is for the usage of DC voltage systems. It has also not concluded if the home or the office will be the best place for these systems. However previous research (Kinn, 2011a, Chapter 5) has looked at this and further analysis is left for further work.

### **7.3. Wider implications derived from the approach of this research**

#### **7.3.1. Are policy makers skilled enough?**

Many of the global sustainability challenges are directly connected to the availability of energy and electricity, yet the interview data suggests that within sustainability policy formation and enactment, very few if any engineers are directly involved in sustainability and energy policy making. Much of the governance of policy making is in the hands of political scientists, economists, and social scientists. While sustainability and some of the global challenges are caused by technology, the engineers and technologists are often bystanders, as consultants to be called upon and not heavily involved in actual policy making (Section 5.5.1). It was found that policy-makers and associated decision makers do not necessarily possess the technical skills needed to provide solutions for these global challenges. Furthermore, it was stated by at least two of the interviewees that the sustainability and policy making fraternity do not understand engineering language and engineers cannot speak the language of the policy fraternity. This is, therefore, a barrier that can be overcome through interdisciplinary collaboration, knowledge transfer and education. However, at this time there are clear barriers between the fraternities with very few boundary spanners. This opens up the argument as to how technical is sociotechnical theory, given that engaging in such problems

is mainly carried out by non-technical people? It is concluded that there is a need for closer integration of these two fraternities through knowledge transfer, which will break down this barrier and increase the number of experts that create bridges for boundary spanning.

### **7.3.2. Top-down or Bottom-up approach?**

Which approach should the transition take? Should it be top-down, beginning with government/policy makers, then a transition to the market and ending with research, or should it start with rigorous research then bring in the government/policy makers and end with markets?

This research has found that policy makers play a crucial role within the transition process and without the confidence imbued via policy instruments, markets will be reluctant to engage with this or any transition (Section 5.9.2). The question is: what should be the catalyst for this transition, policy or research? This research sees policy as the top-down approach, whereby policy gives confidence to the markets to invest in research that develops the next generation of DC systems, all geared to fulfil the policy frameworks. Research on the other hand, starts by developing the technology, then standards and then creates the environment that shows that the technology is in alignment with Government energy policy. It then formulates the discussion around all the sociotechnical advantages of the technology thus showing further alignments with Government policy. At this stage the policy makers become an integral part of the transition process helping to take the technology out of the niche and into the mainstream. This research labels the research route, the bottom-up approach. The development of the GSM technology is an example of a standard that drove the market from the bottom-up (Section 5.9.1).

From the literature it is concluded that many of the global challenges are ‘wicked problems’. One of the things that often exacerbates wicked problems and can cause secondary problems is the top-down governmental approach to resolving the issues (see Section 6.7). The main example highlighted by The Conundrum is UK Government energy policy that is supposed to reduce the Carbon emissions from the electricity system, yet it advocates the usage of coal and nuclear power for electricity generation, which is detrimental to the uptake of renewables. A second example is the policy of advocating large wind farms, which because they are

intermittent, required the national grid to be upgraded and smartened. This then opened up the problem of cyber-attacks, which brought in the need for cyber security, a chain reaction that has been costly to all UK consumers. It is therefore concluded, that since many of the global sustainability challenges have been challenging societies for many decades, it is preferable to start this transition using the bottom-up approach.

Furthermore, this research states that the development of DC voltage systems standards should develop out of an independent research network and not through market mechanisms. It has been shown that the market does not always produce the best efficient or sustainable solution, as it is more motivated to make profit than to produce a system that will be energy efficient and sustainable (Section 5.7.1). It also has the tendency to take the easiest route to market by piggybacking on already available standards which may not be best suited for the transition to DC systems. The literature and the interviews identified two standards that have been borrowed by researchers and developers of DC systems. These are the 48 Volt standard for communication systems and the 380-400 Volt standards for datacentres that have been cited and used for DC research and bespoke home appliances (see Section 5.5.3). As this research has not been able to identify the research behind the decision to borrow these two voltage standards, it is therefore concluded that this is another reason to follow the bottom-up approach that starts with rigorous research.

### **7.3.3. Is the transition to DC voltage systems a wicked problem?**

Transitioning to DC is seen as a market transformation project that is so complex it can be thought of as being a wicked problem. A case study in Indonesia, where a single man was able to galvanise a whole community to tackle the many societal problems that coalesced into a wicked problem, showed that through the use of a bottom-up design approach the problem was tackled. Although, this is only a single case study and other bottom-up approaches to wicked problems were not found in the literature, this research still concludes that the bottom up approach is the best chance for success (Section 6.7). In the literature that discusses what are perceived as wicked problems, there are hints about the success of community-based projects being more successful than policy-based solutions. However, besides the Indonesian



case study, the bottom-up approach was not found to be associated with any other methodology to dealing with perceived wicked problems.

This research has shown that by breaking down the transition into its phases and components, starting from the consumption side, a transition framework can be developed. By sequencing a chain of smaller transitions over a 43-year period the transition becomes more defined and less wicked. Therefore, it is concluded that the transition to DC voltage systems, which could be thought of by someone who has not taken this bottom-up approach as being possibly a textbook '*wicked problem*', is in fact much less wicked and potentially solvable.

#### **7.3.4. Technical and institutional incumbency**

The Conundrum (Section 3.5) highlights, that while niche technical solutions exist, they are not at this time able to proliferate within the regime and become dominant. The main barriers for new technology are the existing technology and institutional resistance. The many reasons for this include: capital already invested in technology that still has a long life expectancy, vested interests of the owners of capital who do not want to end up with 'stranded assets', market resistance from the energy market, institutional mind sets, and the political will to keep the status quo.

The mind set over the last 130 years has only seen the electricity system as being centralised AC voltage. It is concluded that at this time distributed DC voltage systems are seen as 'outsider knowledge' (Section 6.6.2), even by electrical engineers. Therefore, in order to overcome institutional barriers to the transition to DC voltage systems, knowledge transfer is essential.

#### **7.3.5. Technical innovations making the transition more possible**

This research has highlighted many technical innovations that have over the last 65 years provided many components of the DC electricity system (see Figure 2.4). At this time there are DC generating systems, electronic loads that consume DC voltage, home battery systems that store electricity as direct current; all that is missing are domestic and small office DC appliances and a DC ring main for the built environment. In fact, the whole technology for the

electricity system is moving towards distributed generation. It can be concluded that left to market forces, as has been seen in Germany, distributed electricity systems will proliferate. Therefore, the discussion by this research with regard to the advantages of distributed generation versus centralised generation may be overtaken by market forces. However, how the market will proceed with DC voltage for consumption is still not known.

So far, the market and much of the engineering world that is looking at DC voltage, sees the DC voltage market as developing within the office environment (Section 6.6.2 part 2). This is because the market sees more profit within the office retrofit cycle of five years than within the domestic retrofit cycle of 30 years. Also, since within the UK's energy policy, energy security and energy independence are not seen as paramount, the approach to using distributed DC voltage, even by its advocates, only follows the market and looks at the office environment. Those pilot projects that do look at domestic usage of DC voltage are still only looking to transpose the simple functionality within the office to the home. This means that the domestic DC pilot schemes only look at the limited usage of DC voltage for IT, car charging and lighting systems. They are not looking at its usage for all energy consumption purposes within the domestic environment. It is therefore concluded, that in order for a quicker proliferation of DC systems to come to fruition, the UK's energy policy must make energy independence with energy security its focal point, with its energy trilemma becoming secondary.

#### **7.4. Implications for the MLP as a transitions theory**

The multilevel perspective on sociotechnical transitions is a 21<sup>st</sup> century theory that seeks to understand the details of the processes behind transitions. The field of sustainable energy transitions has used this theory to understand the development of sustainable energy transitions. This research has chosen this theory as its theoretical framework to help in the understanding of the transition within the UK from the incumbent centralised AC electricity system to one where distributed DC is proliferate. The question is: what are the implications for the theory with respect to what has been learned through this research?

#### **7.4.1. Historical case studies or future transitions**

The MLP has been used extensively to help in the understanding of historical transitions and is useful in teasing out interesting sociotechnical perspectives as to how and why a transition took place. Scholars use the theory to look back in order to gain meaning and understanding about an historic technical transition, see Section 3.1 for some of these case studies. What this research does is use the MLP to look forward, to drive a future transition, something that has not been widely seen within the literature. In the historical analysis of a transition, the decision or mechanism for the change that happened has already taken place. However, when trying to understand what decisions may need to be made for a future transition, the MLP has some weaknesses. Some of the questions highlighted are as follows: Where in the conventional three levels are decisions, and plans made? Where do the people making the decisions sit within the MLP? How do the mechanisms of change enable the transition? Transition scholars may answer that this all takes place within the regime level. This may be correct, but where within the regime? It is therefore concluded that as a tool for framing future sociotechnical transitions the conventional MLP, as it stands, contains some issues when applied to future transitions.

#### **7.4.2. Institutional structuration**

Transition scholars have in the past looked to management theories to frame the decision making processes and have identified institutional structuration as being the place where change takes place, which has been identified as being within the regime. The conventional model of the regime is depicted as consisting of interconnected multi-actor networks (Figure 3.3), where the actors and sociotechnical networks sit together on the same 2-dimensional level (Figure 3.2). However, there seems to be no specific place for institutional structuration to take place other than at the same level of the multi-actor networks. This poses difficulties for scholars who try and use this theory as a tool for framing future decisions. Where do the mechanisms for institutional structuration fit in? This is identified as an area for future development.

#### **7.4.3. The regime is more complex for future decision making**

To understand how a future transition will take place, there is a need to know where the core processes for decision making take place. This research was not fully able to identify where in the conventional theory this actually took place. Since the regime is a construct that in many cases will depend on the definition of the unit of analysis, as it stands in the conventional theory, it lacks the ability to define details of what is happening within a transition. It is possible that what is happening within the regime level is much more complex than is depicted within the conventional model.

This research still has confidence that the MLP is an appropriate model for framing a future sociotechnical transition. However, as it stands there was difficulty in placing the details derived from the data within the conventional sociotechnical regime. This research has proposed that the regime level should not be understood as a two-dimensional plane, where everything within it happens on the same level, but it should be depicted as a three-dimensional column with up to seven layers of complexity (Section 3.5.1). It is tentatively concluded that by teasing out the regime level into 3-dimensions, the model is able to show where within the sociotechnical system decisions take place.

When trying to understand The Conundrum, the usage of the term regime within the academic literature was seen as confusing (Table 3.2). What has been defined as multi-actor networks were sometimes referred to as ‘the regime of’ the thing under discussion, i.e. the coal regime. As part of trying to frame this future transition, it became confusing in terms of which elements of the sociotechnical electricity system sat where within the regime. Following on from identifying the regime as being three-dimensional it was considered that clearer naming of the components within the regime would give a better understanding of how they fitted together. The multi-actor networks were relabelled the social and technical networks, instances within a network were labelled institutions, and the decision-making processes and mechanisms are the institutional structuration, which also incorporates the actors. Thus bringing institutional structuration into the 3-dimensional regime of the MLP helps in the framing of future transitions.

This research has identified from the GEA Report that there is a knowledge gap in understanding the regime within energy transitions literature. The 3-dimensional model of the regime potentially begins to open up a better understanding about what is happening within the regime.

#### **7.4.4. Landscape – control and mediation**

The conventional MLP theory sees the landscape pressures on the system as being exogenous to the system under analysis and slow moving. A latter description of the theory added external rapid shocks and long term changes in a certain direction, trend-like patterns (Section 3.2.2), to the dynamics within the sociotechnical landscape. The question is, is there any element of institutional structuration within the landscape? Do actions of the actors connected to the sociotechnical system have any influence over establishing what the landscape pressures will be? Furthermore, given the conventional MLP understanding of the landscape, what is the extent of its externality to the system under analysis and what is its time frame for the speed of change? These questions emerged when trying to understand The Conundrum.

Energy policy is an integral part of the sociotechnical electricity systems, and resides within the social networks of the regime. During the policy forming process, many actors from many different sociotechnical systems form committees to formulate the policies. While government policy makers, i.e. Government Ministers reside within the political system, when they are involved with energy and electricity policy, they are directly influencing the system and cannot be said to be exogenous to it. It has been shown in Table 3.5, that in different countries it is energy policy decisions that dictate what the primary and what the secondary landscape pressures will be on the electricity system.

The use of the term landscape by transition scholars, is supposed to indicate that just as changes in the physical landscape take a very long time, so too do changes in a sociotechnical system. However, the interview data suggests that the time horizon for politicians and therefore for much of the UK's energy policy is only five years. As this is being written, the new Prime Minister, Theresa May, has announced the abolition of the Department of Energy and Climate Change and the forming of a new Department of Business, Energy and Industrial Strategy. Angus Brendan MacNeil MP, Chair of the Energy and Climate Change Committee

(Ukparliament, 2016), has raised many questions about the future direction and scrutiny of energy policy. Such a decision for the Prime Minister is bound to introduce changes into the landscape of the energy and electricity system. Further to this, in July 2016 the Prime Minister put the project to build a new nuclear power station on hold, a deal that took many years to develop was put on hold overnight. Also found in the literature was the decision by Germany to close down its nuclear generation capacity (see Section 3.5.3). It is concluded that many of the landscape pressures on the electricity system are in fact within the control of policy makers, are more endogenous to the landscape and faster moving than the conventional theory suggests. This new understanding of the dynamics of the landscape begins to consider some of the issues highlighted by Geels with regards to the landscapes' definition and impact, which were identified as a knowledge gap in Section 3.4.1 above.

#### **7.4.5. Sociotechnical transitions of a multi-system system**

From the interview data it was shown that for the electricity system to transition to distributed DC voltage systems there has to be an alignment of many social networks. These networks have been depicted as being within the electricity regime. Some of these are internal to the electricity system, while others are external but operate on it. One example is energy policy, on one hand the policy is within the electricity system but on the other hand the policy makers are external to the system. It could be argued that the electricity system, which is part of the energy system and is owned by the market, being a regulated industry is interconnected to the political system. There are therefore four interconnected systems, the energy system, the electricity system, the market system and the political system.

The components of any external systems that interact with the one under analysis can be depicted as being social or technical networks within the regime of the system under analysis. The question is, are there any interconnection or impacts of the external system on the system under analysis? i.e. do we ignore the rest of the external systems that currently do not seem to have any direct impacts on our system? Perhaps the tentative solution given below will show the importance of taking into consideration the full interconnections of all four systems.

#### 7.4.6. A possible solution to The Conundrum

The Conundrum has been defined as follows: how is it possible that there exist perfect scenarios whereby windows of opportunity have opened in the energy landscape, and allowed many niche low carbon technologies to develop, yet the incumbent regime keeps its power and is able to deflect any destabilisation from the niche? (Section 3.5). The Conundrum can also be expressed with reference to the electricity system as follows: how is it possible that there exists renewable technology that could help reduce carbon emissions and fulfil energy policy, yet they remain largely in the niche and not able to substitute or destabilise the usage of coal and nuclear for electricity generation? Given that there are four interconnect systems, it is concluded that when trying to understand a transition within interconnected systems, i.e. The Conundrum, a solution must look at all interconnected systems. To properly understand how the electricity system can transition to DC voltage, the problem must include all connected systems, thus the goal is to solve a multi-system problem and not just the single electricity system.

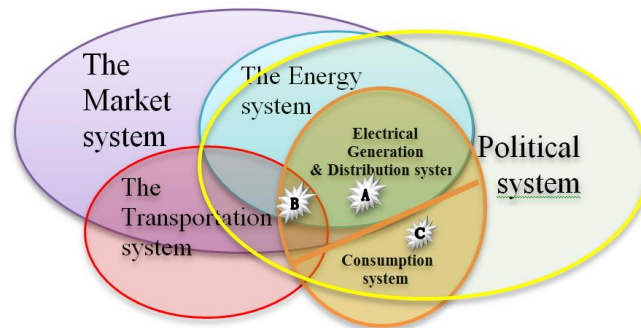


Figure 7.1 The multi-system associated with The Conundrum.

Renewable energy policy can be said to operate within the electricity generation market, which is at 'A' in Figure 7.1. However, Government policy aimed at reducing carbon emissions via electrification within the transport sector 'B', gives it another avenue to reduce CO<sub>2</sub> emissions other than with renewables for electricity generation. Rooftop renewable generation, as part of energy policy, is at this time at 'C', which is mainly out of the market system and in the hands of the homeowners. By having other opportunities for CO<sub>2</sub> reductions the Government has wriggle room to continue to use fossil fuels to generate electricity, without increasing the overall CO<sub>2</sub> emissions. This policy restricts and reduces the

opportunities for renewable technology to emerge from the niche and transform the electricity regime, hence the existence of The Conundrum. A possible solution to The Conundrum can be understood where the energy policy could move to within the multi-system configuration shown without compromising on its core goals.

Many people cannot afford low carbon systems, such as installing rooftop solar panels and having a battery backup system in their homes. However, if the business model for low carbon systems could incorporate the ownership of rooftop solar, like the ‘rent-a-roof’ business model (Center For Sustainable Energy, 2015), that is able to provide profits for the incumbent utilities and associated businesses, or public-private-partnerships (Bradford, 2006) where the utilities can operate as energy service companies (Pätäri and Sinkkonen, 2014; Scott, 2014), this will provide profits to the ‘market system’ thus aligning their goals with low carbon generation. This brings the domestic electricity system into the market system. The greater the amount of distributed low carbon generation the less fossil fuels will be needed to be burned, thus reducing the carbon footprint of the energy system. Added benefits of a low carbon distributed system are increased energy independence and security for the householder, and an increase in the UK’s energy security, thus benefiting political aims of the government. It is therefore postulated that a possible solution for The Conundrum is to move rooftop distributed DC generation systems into the market system, which moves the line up to the dashed position, thus satisfying landscape pressures on all the interconnected multi-system, which is at ‘D’ in Figure 7.2 below.

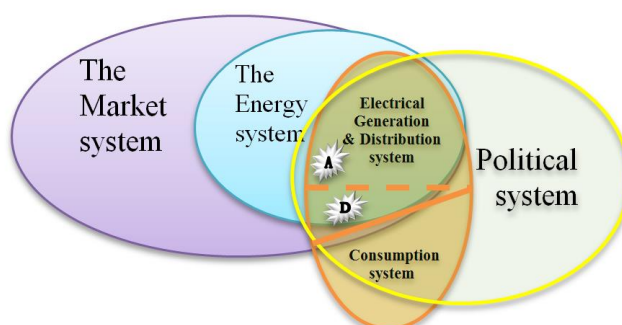


Figure 7.2 Aligning the solution with all four systems at point ‘D’.



It is therefore concluded that when looking at future sociotechnical transitions, it is important to include closely associated interconnected systems and look for a solution that satisfies the whole multi-system system.

#### **7.4.7. Usefulness of the multilevel perspective as a tool for future transitions**

The conventional multilevel perspective theory as it stands is too over-arching for the details required when mapping details for a future transition, i.e. it is of a too high order. By opening up the regime into a three-dimensional design of five or seven levels, institutional structuration can be incorporated within the sociotechnical regime. Identifying the components of the system as technical and social networks within the regime makes it easier to use the MLP to frame all the components without ambiguity and as a tool for framing future transitions. According to the conventional understanding of landscape as being exogenous and slow moving, policy decisions placed on the energy or electricity system, that cause regime shifts should be impossible.

However, by understanding that in a multi-system approach to the problem, the landscape pressures can be endogenous and relatively fast moving this helps in understanding how institutional structuration can catalyse transitions. With this new understanding of the regime and landscape levels of the MLP, as a theory it become a better tool for framing future transitions. It should be noted that the methodology to approach this deeper understanding of the regime within the MLP was to start with actions within the regime and follow it up to the regime level and then to the landscape. This process thus took a bottom-up approach.

#### **7.5. Contributions to knowledge**

The first contribution to knowledge was to begin to close the knowledge gaps identified through the literature review (see Section 2.6). Three contributions are discussed here, one was to develop transition pathways to distributed DC voltage systems for consumption within the built environment, two was the sociotechnical characterisation of the electricity system and three was to identify how society is affected by the loss of electricity. However, the last two were only the objectives to reach the aim of this research which was to develop a transition pathway.

### **7.5.1. Developing a transition pathway**

Through the literature review the sociotechnical electricity system from a UK perspective was found to be under researched. Through primary data gathered via interviews, and data from the literature that was used to inform the methodology approach that shapes this research, a more detailed understanding of the whole sociotechnical UK electricity system was gained. This identified the social networks within and connected to the electricity system, the institutions and some of their more important structurations, the boundary points between institutions and what is needed for boundary spanning. This led to a list of key processes, which operate within specific phases of the transition pathway. The result was an initial transition pathway for DC voltage systems proliferation.

There are many uses for this transition pathway, particularly as part of any future funding proposal for a DC project. As it has many details, not all of them would be of interest to any particular person. For example, policy makers may be interested only in the different timeframes, and the stages where they need to interact with the project. Similarly, house builders would concentrate on Phase 4, and funding bodies may only be interested in the phase that is pertinent to the present funding bid. Therefore, as a tool, the whole time-line as depicted in Figure 6.4 will have to be reproduced to fit the audience, or the part that is pertinent to them should be highlighted. This research would like to see future researchers develop it with more details, and as a framework that can be transposed for other sociotechnical transitions.

### **7.5.2. Complexity of sustainable energy transitions**

The characterisation of the system highlighted some of the institutional structurations and some of the barriers to the transition, as well as boundary points and boundary spanners. When the whole system was put together and a complete multi-system system emerged, it was apparent that the sociotechnical electricity system is quite complex. At a first glance, the transition to DC could be identified as a wicked problem, however by approaching the problem from the bottom-up it was possible to show that a pathway does exist for the transition (section 6.7). This led to the conclusion that future transitions could use the bottom-up approach for developing solutions for complex sustainability problems.

By understanding the transition pathway using a more data-lead approach through primary data collection, it then starts to unpack the complexities of some of the underlying institutional structurations. This led to reconsidering the conventional understanding and definition of, and what actually is happening within the regime and landscape of the MLP model and the ability of a niche to gain traction against the incumbent regime, (The Conundrum).

Through understanding the problem of transitioning to DC as being a complex multi-system issue, this led to considering that perhaps the relationships between the different interconnected systems and the institutional structuration within these other systems, impacts the transition in the electricity system, i.e. structuration of external but connected systems impact the system under analysis. It is therefore postulated that the complex interconnections between politics, the markets, and how energy and electricity are dealt with within sustainable transitions, could somewhat go towards answering the problems highlighted by Geels and Lockwood, which lead to the development of The Conundrum (see Section 3.5).

### **7.5.3. Electricity and societal needs - a contribution to city resilience**

During this research, electricity was identified as being under represented within the disaster literature. Also, as part of identifying the advantages of distributed DC over centralised AC systems the subjects of sustainability within cities and city resilience were looked into. It was concluded from the literature review and some of the interviewees, that the effects of the lack of electricity on people's daily lives and to the functionality of a city were neither well understood, nor central to the sustainability and city resilience debate. This research has highlighted many of the detailed effects the loss of electricity has on the functioning of a city and on people's liveability. It postulates that city resilience and people's future long term liveability can be enhanced through the usage of distributed DC voltage systems. However, at this time this subject is under researched, this might open up a new area of research that considers in more depth the impacts of electricity systems on societal issues connected directly and most importantly indirectly to the usage of electricity, i.e. the impact on society of failure chains that arise out of the loss of electricity.

## **7.6. Some limitations to this research**

This research is a ‘thought experiment’, it looks at a future theoretical transition and is thus constrained by some limitations. This first, is the location of the proposed distributed DC systems, i.e. in the UK. The usage of such systems would be more easily implemented, and perhaps more appropriate, in an area of the world that does not yet have a connection to the electricity grid. However, due to budgetary constraints on this research, the focus has only been on the UK’s electricity system.

### **7.6.1. Early stage research**

The transition pathway developed in this research shows that the transition to DC starts at the proof of concept phase, developing DC appliances. This research is therefore working on a future technical system that is not yet available, which puts this research within a semi-vacuum, as it cannot be based on known engineering. For example, the DC voltage standard for the home is not yet defined and therefore a full set of DC home appliances does not yet exist. This makes it impossible to totally compare and contrast the centralised AC system to a distributed DC system and the technical DC electrical system to an AC system. While based on primary and secondary data, like any horizon scanning research into possible future systems, this research has a huge theoretical skew to what looks like a straight forward technical problem, as the specification of any future DC system is not yet known.

One point to think about is that this research takes place within an emerging field of distributed energy generation and distribution system. The time horizon of this project was four years. Over this time period many changes and developments have occurred that took the possibility of transitioning to distributed DC systems one step closer. These include: the downward spiral in the cost of renewable generation systems, an increase in market involvement in ownership of domestic solar systems, including through schemes like ‘rent-a-roof’, changes in energy policy, like the Green Deal and feed in tariffs, and now the launch of different home energy storage systems. These technological and policy changes are constantly changing the whole research problem and solution. This could mean that developments in the market could overtake the bottom-up approach of the transition framework developed in this research.

### **7.6.2. A theoretical transition**

The quality of a piece of scholarly research based on an historic transition will depend on the researcher's ability to gather and analyse known data. However, when the research is about a future transition the researcher needs to add a layer of theoretical analysis and to some point some futurology to the research. This can be very subjective and bound by the knowledgebase and 'bias' of the researcher. Therefore, fundamentally a theoretical future transition is going to be more complex than an historical one. It becomes a thought experiment that should yield different possible solutions. However due to time constraints, only one possible transition framework for the transition to DC voltage systems was developed. With each technological advancement mentioned in the previous section, this transition takes one more step out of the realms of theoretical towards a practical solution.

### **7.6.3. Inertia of the current UK system**

The centralised electricity system has been operational for over 130 years. Many engineers encountered during this research, including those who declined to be interviewed, could not see any reason why the present centralised AC system should be changed. This research believes them to be locked-in to the way things are done and they therefore see no reason to change. While a finding in itself, this acted as a barrier to data collection. Potential interviewees and some of the actual interviewees, did not comprehend the societal need for energy independence with security and the potential role distributed electricity systems could play. This was a barrier to the data collection as some engineers were unwilling to engage with distributed generation and DC systems. This led to some people been unwilling to be interviewed, or when interviewed viewing DC voltage as outsider knowledge.

### **7.6.4. Scope of primary data capture**

As explained in the methodology chapter, extensive embeddedness into all the social networks using ethnography would have provided very comprehensive knowledge about institutional structuration across the whole sociotechnical system (Section 4.3.1). This was not possible due to resource constraints. For these same reasons, it was not possible to carry out more than 20 interviews of experts from across all the social networks. As this research used

the bottom-up approach, it would have been desirable to have interviewed more home appliance and systems manufacturers. This would have given a deeper understanding of the structuration within that industry. As this was not possible, the manufacturing sector is under represented within this research.

Most of the lead researchers who were interviewed, who could be said to live within the sustainability fraternity, were not conversant with the technical side of the energy and electricity system. While this led to the conclusion that many scholars within the sustainability fraternity do not interact with those in the electrical engineering fraternity, and vice versa, it also caused many potential interviewees to decline interviews as they felt they were not able to discuss the technical aspects of the sociotechnical system. Of the 20 interviewees, only four were able to answer both the technical and non-technical questions.

#### **7.6.5. Validation**

This research uses a multi-method single case study that uses both primary and secondary data each from multiple sources for its data gathering. This means that many of the codes identified in Table 5.3 were identified from multiple interviewees, thus the themes were formulated from multiple sources. Throughout chapter 5, it can be seen which interviewees and how many, coalesced to form the contents of each theme. As such, the identifying of the themes and the contents of the transition time-line (Fig 6.2) come from multiple sources which provides a high degree of internal validity and robustness (Section 4.3.5).

The sociotechnical characterisation of the electricity system was not identified through the literature review and was therefore identified as a knowledge gap (Section 2.6.2). This research identified the social and technical networks (Figure 3.6) of the UK's electricity system as a single case study of a developed country's national electricity system. As this is the first time such a characterisation has been carried out, it could be said to be a 'critical' and a 'revelatory' case study (Yin, 2014, p. 51). These networks are generic to many electricity systems across the developed world and thus reflect a generalised commonality of systems. For these reasons, the use of a single case study is validated.

It might have been desirable to review the final transition framework with **all** the interviewees. However, this research is multi-disciplinary, touches on a wide range of diverse subjects, and it has been shown that almost all of the interviewees viewed questions relating to subjects out of their field of expertise as outsider knowledge. This was especially so with the interviewees, including the engineers, who have never been involved with the technology of DC systems, and who were not expected to be able to answer questions on subjects out of their expertise (section 4.6.4). Therefore, it was determined that reviewing the whole transition framework with each interviewee, knowing that much of the contents of the framework exists outside their expertise, would be problematic and add little value to what is already known. However, each interviewee was sent an anonymised transcript of their own interview for verification.

## **7.7. Further work**

This research has highlighted knowledge gaps and has discovered new points of interest that require further research.

### **7.7.1. City resilience and sustainability transitions**

In order for this research to characterise what happens to a city when a disaster strikes, it had to rely on secondary data (Saunders et al., 2009, Section 8.2 ) found in the literature. There is therefore a need for further research to gather primary data into understanding how the functionality of a city is affected by the loss of electricity and to potentially develop an understanding of how distributed systems can increase a city's resilience. Further research could include specific details on the direct impact of power outages on: the usability of the built environment, the living standards and conditions of the survivors, how post disaster impacts could be affected if the electricity system was still operational and what changes are needed to the electrical system to reduce the impacts of the loss of electrical power when a disaster strikes. Further work is also needed to identify how many of the global sustainability challenges can be positively impacted by the usage of distributed DC voltage systems.

Knowing the reliance and therefore the impacts due to a power cut on society, only identifies the problems; this is only half the research. What is then needed is research into the cure,

which is the technology that could provide distributed DC systems, that could mitigate against the problems caused through a breakdown of the centralised system.

More research is needed to identify how distributed DC systems could provide the UK with energy security and energy independence and to identify any implications such systems could have on enhancing national security.

#### **7.7.2. For people who are not yet connected to a national grid**

One of the findings of this research is that many experts in the field of energy and sustainability do not see any reason why the UK should think about transitioning to distributed DC systems. This is because the UK already has a centralised system. However rural areas in the UK that are off grid, and for the 1.4 billion people worldwide who in 2012 (GEA 2012) were not yet connected to any electricity, distributed DC systems may be a solution. Therefore, more research is needed to identify ways of using distributed energy systems, which may include DC voltage systems, for those people not yet connected to a national grid system. This should not just be to provide a basic system for lighting and IT communications, but must also include cooking, refrigeration, thermal comfort and all other household needs.

#### **7.7.3. Enhancing the multilevel perspective model**

While this research has endeavoured to gain a deeper understanding of the regime and landscape aspects of the MLP model, it has only been tested against the electricity system. Further research into transposing the new understanding of the MLP should be carried out to see if different historical as well as future transitions can be better understood. Perhaps future work can look at opening it up into a deeper and broader model.

This research was limited in how much data about institutional structuration of the social networks within the energy system could be gathered. Institutional structuration within the sociotechnical energy system is therefore a place where more research is needed. This research has identified sustainability transitions as taking place within an interconnected multi-system. Therefore, further research is needed to understand institutional structuration, of



all connected systems and boundary interactions between all the systems. By doing this the MLP could be then used as a tool to understand multi-system problems.

#### **7.7.4. Developing a generalised transition framework**

Further work should be carried out to rigorously test the transition framework developed by this research for other sustainable transition problems. This may lead to developing a generalised framework for future complex transition.

#### **7.7.5. DC in the built environment**

The advantages of using decentralised electrical systems have been highlighted, however, at this time the use of DC as a main electricity source for the low powered user needs more research and development as well as new extra-low and low voltage regulations and standards, before DC voltage can be rolled out for general usage. More research is needed to increase the awareness of distributed DC for domestic use as at this time the market is mainly concentrating on the office environment.

Further work needs to be carried out that focuses on the ramifications of distributed DC systems of government policy. This should not only include energy and national security policies but all policies connected to global sustainability challenges.

### **7.8. Final word**

This research is a theoretical future technical transition based on gathered data, about the known energy and electricity system, from experts and from published data. Therefore, it is concluded that this research is only a tentative look at the transition to distributed DC and can only be one possible blueprint, for this and any other technical transition. This blueprint will be greatly enhanced through further research and technical innovations. If, as the research suggest, distributed DC could provide solutions for many of the 21<sup>st</sup> century's global challenges, what would now be needed are; technology champions, who with foresight and tenacity will succeed in building a coalition of like-minded people who, over time, will bring to fruition the transition to the proliferation of distributed direct current voltage systems. Thus, ushering in the era of distributed energy systems that will begin to provide energy independence with energy security.

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## Appendix 1 Extracts from the GEA (2012) that were used to identify non-technical aspects of the electricity system

Below are extracts from the conclusions in Chapter 25 of the GEA report. The words in bold identify possible non-technical aspects of the electricity system, that were used to build Table 2.1 in Chapter 2.

*“Energy transitions are long-term, socially embedded processes that involve changes in **production and consumption** patterns, **knowledge, skills**, formal and informal **institutions**, and the **habits and practices** of the actors involved.”* (GEA 2012, Section 25.10, p. 1786)

*“Problem solving can be accelerated by developing channels for **access to knowledge** and information. These channels consequently encourage the more rapid diffusion of new energy technologies. The beneficiaries would be manifold, going beyond local **governments, research bodies**, and the **banking and business** sectors to include agricultural extension services, **energy users**, and intermediaries such as urban transport and **utility companies**, architects, and **builders**.” “To encourage a more diversified set of criteria for rewards, such as **research grants** and promotions, policies will need to be put in place that stimulate and support linkages between research and users – whether in the business, health, **government, NGO**, or other sectors (Section 25.7.2). **Research funding** will also need to be made available for this purpose.”*(GEA 2012, Section 25.10.2.1 p. 1788).

*“The **higher education system** is crucial for sustaining an energy transition, yet current practices will need to change if it is to play this role. The long-term and uncertain nature of energy transition processes requires flexibility that standard discipline-based **educational and training** programs do not often provide. This at least suggests there is more need for **interdisciplinarity** in graduate, postgraduate, continuing education, and training programs. In many countries, this will require **policy** changes at the national and **university** levels to create this flexibility now and thus strengthen the capacity for adaptive curricula changes as the relative importance of issues, technologies, and challenges change over time.”* (GEA 2012, Section 25.10.2.2, p. 1788).

*“Government, therefore,, will be one of the key actors in the transition process at local, national, and international levels. Developing and keeping a focus on transformative change, however, cannot succeed in the absence of broad-based support, continuous dialogue, and a long-term, systems-based approach to change.”*(GEA 2012, Section 25.10.2.4, p. 1790).

*“Societies and organizations differ in the extent to which established habits, practices, and norms favour interaction and dialogue or more hierarchical patterns of communication. Until recently, dialogues have not featured centrally in project planning and development.” “... For dialogues to work, confidence-building measures that recognize the legitimacy of local concerns, interests, and needs, as well as take account of the informal institutions shaping the behavior of actors involved in the change process, are essential in gaining broad societal support for an energy transition.”* (GEA 2012, Executive Summary to Chapter 25, p. 1748).

*“GEA makes the case that energy system transformation is possible only if there is also an **interactive** and iterative transformation of the **policy and regulatory** landscape, thereby fostering a buildup of skills and institutions that encourage innovation to thrive, create conditions for **business to invest**, and generate new **jobs** and livelihood opportunities.”* (GEA 2012, p. 93).

## Appendix 2 DC standards

British standard 7671:2008 2011

1. Appendix 1 of British Standards to which reference is made in BS7671:2008 2011 (very many)
2. Appendix 9: DC. System Types gives schematics of different dc wiring configuration
3. Section 708 deals with caravans wiring system ( should be the same for a house)
4. Appendix 2 Statutory Regulations
5. Chapter 13 – Fundamental Principles
6. Annex A444 Measures against Electromagnetic Disturbance.

Acts/ Regulations:

1. Requirements for electrical Installations IET Wiring Regulations BS 7671:2008 2011
2. Electrical Safety, Quality and Continuity regulations 2002 as amended.
3. Electricity at Work Regulations 1989 (SI 1989 No 635)
4. Electrical Equipment Safety Regulations 1994 (SI 1994 No 3260)
5. The Plug and Sockets etc. (safety) Regulations 1994 (SI 1994 No 1768) - made under the Consumer Safety Act 1978.
6. The electromagnetic Compatibility Regulations 2005 (SI 2005 No 281)

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DC STANDARDS LIST; APPLICABLE TO RESIDENTIAL AND COMMERCIAL DC SYSTEMS						
#	Existing Standard Title	Standard Number	Year of Issue	Issuing Agency/ Organization	Applicable Section or Part	Standards Group Member Name
1	Railway Applications - Electric Equipment for Rolling Stock	IEC 60077-3 (Edition 1.0)	2001	International Electrotechnical Commission (IEC)	Part 3: Electrotechnical Components - Rules for D.C. Circuit Breakers	Wolfram Teppan
2	Electrical Installations in Ships	IEC 60092-507 (Edition 2.0)	2008	International Electrotechnical Commission (IEC)	Part 507: Small Vessels	Wolfram Teppan
3	Circuit-Breakers for Overcurrent Protection for Household and Similar Installations	IEC 60898-2 (Edition 1.1)	2003	International Electrotechnical Commission (IEC)	Part 2: Circuit-Breakers for A.C. and D.C. Operation	Wolfram Teppan
4	AC and/or DC-Supplied Electronic Control Gear for Tubular Fluorescent Lamps - Performance Requirements	IEC 60929 (Edition 4.0)	2011	International Electrotechnical Commission (IEC)		Wolfram Teppan
5	Electromagnetic Compatibility (EMC)	IEC 61000-4-17 (Edition 1.2)	2009	International Electrotechnical Commission (IEC)	Part 4-17: Testing and Measurement Techniques - Ripple on D.C. Input Power Port Immunity Test	Wolfram Teppan
6	Electromagnetic Compatibility (EMC)	IEC 61000-4-29 (Edition 1.0)	2000	International Electrotechnical Commission (IEC)	Part 4-29: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests	Wolfram Teppan

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7	DC or AC Supplied Electronic Step-Down Convertors for Filament Lamps - Performance requirements	IEC 61047 (Edition 2.0)	2004	International Electrotechnical Commission (IEC)		Wolfram Teppan
8	Low-Voltage Power Supplies, D.C. Output	IEC 61204-7 (Edition 1.0)	2006	International Electrotechnical Commission (IEC)	Part 7: Safety Requirements	Wolfram Teppan
9	Electrical Safety in Low Voltage Distribution Systems Up to 1000V A.C. and 1500V D.C. - Equipment for Testing, Measuring or Monitoring of Protective Measures	IEC 61557-6 (Edition 2.0)	2007	International Electrotechnical Commission (IEC)	Part 6: Effectiveness of Residual Current Devices (RCD) in TT, TN and IT Systems	Wolfram Teppan
10	Short-Circuit Currents in D.C. Auxiliary Installations in Power Plants and Substations	IEC 61660-1 (Edition 1.0)	2000	International Electrotechnical Commission (IEC)	Part 1: Calculation of Short Circuit Currents	Wolfram Teppan
11	Short-Circuit Currents in D.C. Auxiliary Installations in Power Plants and Substations	IEC 61660-2 (Edition 1.0)	1997	International Electrotechnical Commission (IEC)	Part 2: Calculation of Effects	Wolfram Teppan
12	Short-Circuit Currents in D.C. Auxiliary Installations in Power Plants and Substations	IEC 61660-3 (Edition 1.0)	TBD	International Electrotechnical Commission (IEC)		Wolfram Teppan
13	Electric Vehicle Conductive Charging System	IEC 61851-21 (Edition 1.0)	2001	International Electrotechnical Commission (IEC)	Part 21: Electric Vehicle Requirements for Conductive Connection to an A.C./D.C. Supply	Wolfram Teppan
14	Electric Vehicle Conductive Charging System	IEC 61851-23 (Edition 1.0)	2014	International Electrotechnical Commission (IEC)	Part 23: D.C. Electric Vehicle Charging Station	Wolfram Teppan
15	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-1 (Edition 2.0)	2014	International Electrotechnical Commission (IEC)	Part 1: General	Wolfram Teppan
16	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-2 (Edition 2.0)	2014	International Electrotechnical Commission (IEC)	Part 2: D.C. Circuit Breakers	Wolfram Teppan
17	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-3 (Edition 2.0)	2006	International Electrotechnical Commission (IEC)	Part 3: Indoor D.C. Disconnectors, Switch-Disconnectors and Earthing Switches	Wolfram Teppan
18	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-4 (Edition 1.0)	2006	International Electrotechnical Commission (IEC)	Part 4: Outdoor D.C. Disconnectors, Switch-Disconnectors and Earthing Switches	Wolfram Teppan
19	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-5 (Edition 1.0)	2006	International Electrotechnical Commission (IEC)	Part 5: Surge Arresters and Low Voltage Limiters for Specific Use in D.C. Systems	Wolfram Teppan
20	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-6 (Edition 1.0)	2014	International Electrotechnical Commission (IEC)	Part 6: D.C. Switchgear Assemblies	Wolfram Teppan
21	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-7-1 (Edition 1.0)	2006	International Electrotechnical Commission	Part 7-1: Measurement, Control and Protection Devices for Specific Use in D.C. Traction	Wolfram Teppan



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				(IEC)	Systems - Application Guide	
2 2	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-7-2 (Edition 1.0)	2006	International Electrotechnical Commission (IEC)	Part 7-2: Measurement, Control and Protection Devices for Specific Use in D.C. Traction Systems - Isolating Current Transducers and Other Current Measuring Devices	Wolfram Teppan
2 3	Railway Applications - Fixed Installations - DC Switchgear	IEC 61992-7-3 (Edition 1.0)	2006	International Electrotechnical Commission (IEC)	Part 7-3: Measurement, Control and Protection Devices for Specific Use in D.C. Traction Systems - Isolating Voltage Transducers and Other Voltage Measuring Devices	Wolfram Teppan
2 4	DC or AC Supplied Electronic Control Gear for LED Modules - Performance Requirements	IEC 62384 (Edition 1.1)	2011	International Electrotechnical Commission (IEC)		Wolfram Teppan
2 5	Railway applications - Rolling stock - DC Supplied Electronic Ballasts for Lighting Fluorescent Lamps	IEC 62718 (Edition 1.0)	2013	International Electrotechnical Commission (IEC)		Wolfram Teppan
2 6	Occupied Space Standard	EMerge	2013	EMerge	Commercial Building use of DC	Doug Houseman
2 7	Data/Telecom Center Standard	EMerge	2013	EMerge	Commercial Building use of DC	Doug Houseman

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DC STANDARDS LIST; APPLICABLE TO RESIDENTIAL AND COMMERCIAL DC SYSTEMS						
#	Proposed Standard Title	Standard Number	Year of Issue	Issuing Agency/ Organization	Applicable Section or Part	Standards Group Member Name
1	Instrument Transformers	IEC 61869-14	TBD	International Electrotechnical Commission (IEC)	Part 14	Wolfram Teppan
2	Instrument Transformers	IEC 61869-15	TBD	International Electrotechnical Commission (IEC)	Part 15	Wolfram Teppan
3	Instrument Transformers	IEC 61869-9	TBD	International Electrotechnical Commission (IEC)	Part 9	Wolfram Teppan
4	Electricity Metering Equipment (a.c.)	IEC 62053-41	TBD	International Electrotechnical Commission (IEC)	Part 41	Wolfram Teppan
5	Electrical Measuring Transducers for Converting A.C. and D.C. Electrical Quantities to Analogue or Digital Signals	IEC 60688 (Edition 3.0)	2012	International Electrotechnical Commission (IEC)		Wolfram Teppan
6	IET Wiring Regulations 17th Edition	BS 7671 2008:2011 (incorporating amendment number 1:2011)	2011	The Institution of Engineering and Technology (IET)		Moshe Kinn



## Appendix 3 Publications

- Peer  
Reviewed
- Title : *Proposed components for the design of a smart nano-grid for a domestic electrical system that operates at below 50V DC*
- Author : Moshe Chaim Kinn  
Publisher: Proceedings of 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe) December 5-7 2011, Manchester, England UK
- Peer  
Reviewed
- Title : *To what Extent is Electricity Central to Resilience and Disaster Management of the Built Environment?*
- Author : Moshe Chaim Kinn, Co-Author: Carl Abbott  
Publisher: *Procedia Economics and Finance*, 18, 238-246. 2014 4th International Conference on Building Resilience, Incorporating the 3rd Annual Conference of the ANDROID Disaster Resilience Network Salford Quays, United Kingdom doi:[http://dx.doi.org/10.1016/S2212-5671\(14\)00936-8](http://dx.doi.org/10.1016/S2212-5671(14)00936-8)
- Book  
Chapter
- Title : *Solar hydrogen energy systems: A magic bullet for global sustainable urbanisation*  
Chapter Author : Moshe Chaim Kinn  
e-book editors: Jenna Condie and Anna Mary Cooper
- This is Chapter 56 in an e-book entitled, Dialogues Of Sustainable Urbanisation: Social Science Research And Transitions To Urban Contexts  
<http://isscbookofblogs.pressbooks.com/chapter/solar-hydrogen-energy-systems-a-magic-bullet-for-global-sustainable-urbanisation/>  
For whole book see International Social Sciences Council website  
<http://www.worldsocialscience.org/2015/08/70-researchers-7-months-1-book-dialogues-sustainable-urbanisation/>
- Conference  
Paper
- Title : *An exploration of the technical and economic feasibility of a low powered DC voltage mains power supply in the domestic arena*
- Author : Moshe Chaim Kinn  
Green Building Power Forum, Anaheim, California, USA , 2009. A Darnell Conference  
<http://www.dciisthefuture.org/papers/>

Input paper	<p>Title : <i>The use of direct current voltage systems to increase a city's resilience and reduce the vulnerability of economic activity from a disaster</i></p> <p>Author : Moshe Chaim Kinn, Co-Author: Carl Abbott</p> <p>Input paper to the Global Assessment Report on Disaster Risk Reduction 2015( GAR15) an output report of the UNISDR <a href="http://www.dclisthefuture.org/papers/">http://www.dclisthefuture.org/papers/</a></p>
Input Brief	<p>Title : <i>The centrality of electricity supply for global sustainable development</i></p> <p>Author : Moshe Chaim Kinn, Co-Author: Carl Abbott</p> <p>Input paper to the Global Sustainability Development Report. (GSDR15) A United Nations report <a href="http://www.dclisthefuture.org/papers/">http://www.dclisthefuture.org/papers/</a></p>
Conferences paper	<p>Title : <i>The socio-technical regime networks associated with the implementation of direct current (DC) electricity in the built environment</i></p> <p>Author : Moshe Chaim Kinn, Co-Author: Carl Abbott</p> <p>Paper presented at the International Postgraduate Research Conference, the University of Salford, Manchester, UK, 2013 (no proceedings were published for this conference, but all presented papers were disseminated via memory stick)</p>
Call for evidence	<p>Submission to the Energy and Climate Change Committee of the House of Commons. Submitted 08/09/2015 evidence number EPC0005. <a href="http://www.publications.parliament.uk/pa/cm201516/cmselect/cmenergy/368/36808.htm">http://www.publications.parliament.uk/pa/cm201516/cmselect/cmenergy/368/36808.htm</a></p>
Oral Evidence published by House of Commons	<p>Oral evidence presented to the House of Commons Environmental Audit Committee</p> <p>Presenter: Moshe Kinn,</p> <p>Conference on the Government's Approach to Sustainable Development, House of Commons October 2015</p> <p>Published by House of Commons under Question 9 of evidence. <a href="https://www.parliament.uk/business/committees/committees-a-z/commons-select/environmental-audit-committee/inquiries/parliament-2015/governments-approach-to-sustainable-development-/">https://www.parliament.uk/business/committees/committees-a-z/commons-select/environmental-audit-committee/inquiries/parliament-2015/governments-approach-to-sustainable-development-/</a></p>

## **Appendix 4 Anonymised example interview transcript**

(I3) is interviewee (MK) is this researcher

### **SECTION 1: BACKGROUND**

#### **A. About you**

1. What is your position within the organisation and what is your main responsibilities? (I3) I work for the property services team which is now being rebranded as the workplace team. I am responsible for setting all the technical engineering standards for my organisation.

2. What made you and your organisation look into the used of DC voltage systems? (I3) in terms of DC voltage systems we are committed to environmental plan of minimising our carbon footprint and DC power gives us a potential option to reduce our carbon footprint and our energy consumption even further.

#### **B. About your Organisation**

1. In which regions of the UK does your organisation operate (e.g. England, Scotland, Wales Northern Ireland)? (I3) all regions, we cover the whole of the UK and we are global organisation employing over hundred 120,000 staff, (MK) does it include international? (I3) Yes include international

2. In general for your organisation, when developing a new project, like for example DC, who inside your organisation or what department has influence on initiation funding, design, development etc.? (I3) that comes through the property services team which is now the workplace team. The input is provided across a number of teams from a project team who actually construct and design the project, a technical operations team who actually receive the project and a standards & compliant team who actually make sure that we actually receive what we have asked to be delivered. The actual customer relies upon the workplace team to develop the design and to provide the facility for the customer to occupy. When I say a customer it could be IT a business group or a building user.

3. For the DC project was it initiated by the customer group or by the workplace team? (I3), the approach to DC would be provided from the workplace team through the technical subject matter expert within that workplace team i.e. myself, and maybe a few other engineers that are party to that particular project. Our standards as they are currently being developed will provide DC powerful as option for consideration not a standard for adoption in its totality. So we will still have options for AC power but DC power will still provide us options with for further consideration.

4. Why does your organisation have policies specifically relating to the use of Direct Current voltage? i.e. What are/were your organisations motives and expected outcome from the use of DC voltage? (I3) at the moment we do not have any standards associated with DC voltage. We have many in terms of AC voltage the DC voltage development or concept within our organisation is at the very early stage it's been develop by myself ostensibly as this option for further consideration and there is some resistance from various people who think that we are not going in a forward-looking way we looking backwards but that is because they don't understand the technology and the options that are available to us at this time.

5. In order to sell the idea you have to show some expected outcomes that would be a positive for your organisation, what are the outcomes that you're trying to sell to show the DC should be used? (I3) there are few aspects, one is the ability to shorten the construction programme adopting DC power and a DC design a second is the reduction in energy consumption in terms of DC and thirdly is a reduction in capital cost associated with the construction of a DC installation and a fourth one I would suggest is the ability to make the infrastructure even more resilient and more scalable by the use of DC technology it allows us to look at the infrastructure in a different way by minimising parts and systems and configuring them in is totally different way.
6. How will your DC systems deal with blackout situation? (I3) it would form part of an infrastructure design that was fault-tolerant and it would provide us with a reduced number of failure points so that we wouldn't be converting power or duplicating the conversion of power from AC to DC and DC to AC at various points in that infrastructure we would be just converting once, so as we take those elements out we therefore increase the reliability of the system, it will be still connected to the AC grid only on the basis that rotating DC machines are not available today for a whole host of reasons they are expensive they are difficult to maintain they can be unreliable and their controls are difficult to manage to provide a really stable output of what is required these days in terms of a stable DC power supply for IT equipment.
7. Does your organisation have support R&D in anyway with respect to energy reduction in the built environment? (I3) yes the organisation is sponsoring me on my engineering degree, in terms of looking at the workplace environment, and the effects on the occupants and the ability to utilise our buildings more efficiently and effectively.
8. Does your organisation have any programs like reduction of CO2 emissions all the reducing the total energy used in the built environment? (I3) yes we have a corporate social responsibility policy, environmental policies which are funded but am I not aware of any other university type funding.

## **SECTION 2: Implementing a DC system**

### **A. Mechanisms for a transition from AC voltage electricity to DC voltage electricity.**

1. What specific systems in your organisation are you aiming to power using DC voltage? (I3) data centres, desktop power supplies, investor trader desks environment, lighting, power over Ethernet lighting, probably that is as far as we would want to go at this time, maybe some elements of HVAC systems.
2. What advantages will/has a DC system provide/will provide to your organisation? (I3) covered before
3. How long does it take in the development of a project in your organisation? (I3) something between six and 18 months. Where will depend on the final project.
4. Does this include getting DC on the agenda, from the first stage of the process? (I3) I would say 18 months would be from the initial stages

3. What were/are the bottlenecks in the development of a project in your organisation and particularly in the DC system? And could you please provide me with any details? (I3) technology awareness is a big bottleneck in terms of being able to convince others that a step change from A/C to DC is achievable that is a bottleneck the next one is certainly finance, all be it the research that has to go into to prove that the DC option is financially cheaper or more effective than the A/C solution that does not exist at the moment, so each time it is a reinvention of the wheel in terms of looking at a project and costing it and providing a cost option between DC and A/C that's a bottleneck that slows things down and then just the actual design process of people having to re-educate themselves in terms of DC again another bottleneck is in terms of does the design and construction team actually understand what they are doing and finally another bottleneck is where do we actually go and buy all this equipment it takes some time to go out and source the right supplier or any supplier that can provide us with DC components.

4. What stage is your organisation at with regard to implementing a DC electrical system? (I3) we are at a day one, we haven't adopted any systems, we are not at this stage on the road or on the journey to adopting DC were at the point where we are having to educate people that DC is actually an option available for their consideration

## **B. About the roles of individuals , firms and regulations in influencing the adoption of change**

1. What skills does your organisation possess to implement a DC project? (I3) at the moment we don't have any

2. I don't mean hands-on skills I mean knowledge skills? (I3) we have a considerable amount of chartered electrical engineers but we don't have anyone with any experience of DC Power distribution so we again need to re-educate those people in what's DC actually is, how it actually distributes, how it generates what components are involved so we are at the point where knowledge is low and the aspiration for DC is low but the technical competency of the individuals is quite high, so it wouldn't take too long for the people that we have to understand DC technology and move on quite quickly I would say about 12 months.

3. Have you yet identify courses books or knowledge base that your people could delve into? (I3) not at the moment I am aware but is not being shared or disseminate to anyone else as of yet.

4. Can you tell me what courses or knowledge that you know is available at the moment? (I3) I'm not sure that there are any courses out there on DC specifically in terms of DC Power distribution but there are a number of DC fundamental books and a number of older generation of lecturers that lecture at universities that are to a certain extent still familiar with DC there are regional equipment manufacturers out there who make DC equipment and there are some like the railways and ships and the crane industry that still rely on DC is still have some level of expertise to call upon the institutions for example the IET have a wealth of information about DC but it is not up-to-date in my opinion.

5. When developing this project, which external people / organisations have you needed to consult on its design and development? (I3) I have consulted with the likes of ARUP with various equipment manufacturers from bus-bar switchgear Schneider Tarasaki a company

called Power Bar electrical contractors to understand where the electrician is on that journey, in terms of are they aware of DC power and are they capable of installing it and testing it and certifying it specifically, there are no standards for certifying DC power at the moment the regulations that exist for DC power are not unified and are certainly asserting not joined together so there is a lot of information in terms of regulations out there but they're not joined together, there is some really good information in some of those.

6. Was it easy to identify and procure DC components or subsystems from these companies? (I3) yes relatively as long as you engage with the large companies like Schneider ABP Tarasaki those type of companies, metering was a particular issue but the likes of Soccermet for instance have a metering solution. Protection systems Bender they have a DC protection solution so there are people out there that do this primarily for the railways more than anything else on the DC traction railways. So there is in my opinion considerable amount of knowledge out there but it is not consolidated or unified into a specific DC segment.

7. Have you had any problems with recruiting any technical skills, people or component suppliers for your (potential) DC system? (I3) have not got that far yet. But talking to various electrical contractors they were totally unaware of what they would need to do in terms of installing and certifying DC installations.

8. For the point of view of systems installation how able are electrical contractors to install such DC system? (I3) at the moment I would say that it is very low, only on the basis that this is a completely new infrastructure subject for the electrician's to install, so I would suggest it is an issue that needs significant review and development in terms of the existing knowledge that these people do actually have on DC. Obviously they do have some in terms of batteries but when you are talking about the design of these systems and more specifically how do you test them with what equipment do you test them and do we have the right test equipment available from the likes of ABLE or MEGA or Fluke, to me there does not seem to be any DC test equipment out there other than the really specialist stuff.

9. If you do install a DC system, will your data centre staff need to be retrained or will new staff need to have a different training for the DC system as compared to the A/C system? (I3) I think training is not quite the right word I think it is an education in terms of DC power once the power is on, it is on so I think the word training should be replaced by education because training and installing DC power for instance what level of training do you need different from installing and A/C cable for instance? it is more of an education in terms of the effects of DC power, the designer DC power in cables and the connections. is it a case of what switchgear does when it opens a fully loaded DC cable, the arc that is created things like that in terms like that, is relatively well understood with A/C but because you have a DC voltage continually energised and a constant current being consumed without passing through a zero point what does it do to DC breaker or DC isolated when it is operated things like that they are the type of things that more education rather than training.

10. Will users need to operate DC equipment differently and therefore need training? (I3) no I don't think so. As long as it has the same output I don't think the actual user is that concerned.

11. Which bodies / interest groups generally, do not particularly have to be in your company, do you see as a positive influence on the adoption of DC technology? (I3) I would

suggest that it is the IT department as they already have the components operating at DC and available at DC, I would also suggest that the engineers within the workplace teams would support DC other than that I am not sure that there is anyone to be honest.

12. Who would you identify as being the DC community that they could have a positive influence generally for the use of DC technology in the whole world not just in your company? (I3) I think it needs to start with institutions supporting DC standards, then it needs standards within the relevant regional communities, we need to see OEMs providing products that will give us the ability to adopt the technology more readily, the universities, the education establishments need to start to educate students in terms of alternative means of power.

13. What about funding bodies? (I3) the Technology Strategy Board I thinks they should put some funding aside in terms of research, and researching DC power and really showing the conceptual benefits of taking it further and then independent OEMs I would suggest need to do more research, and particularly governments like the UK government through the TSB should look to fund DC research.

14. Have you come across any institutionalised negativity to the idea of using DC? (I3) yes I have, but I don't think it is actual specific institutions I just think it is the business environment, and the ability to accept the change I think is the biggest piece given that the question is why do I need to change? What are the key drivers for making the change? Which we have already discussed, people can't see them yet because it is not presented in a way that has any substance behind it and particularly given that there are no unified or coherent standards available yet so is all a little bit messy and until it starts to tighten and have a structure or framework around it, people will remain suspicious in my mind of a change that is not specifically justified or supported through specific standards.

15. Do you see a pathway whereby DC would proliferate? (I3) yes I think there is a pathway, that is what I tried to elude to if there is a support framework from various institutions education establishments that to start encourage and embody DC power into their approach to engineering than I think it will start to develop naturally rather it being forced through the adoption of financial change carbon management and things like that in terms of encouraging people through different means rather than it just being delivered internally from somebody's great idea, let's do this folks, we need to see a bit more marketing of DC power.

16. To reiterate, are you saying it should be a bottom up approach perhaps where it starts off with educating the next generation of university students and being marked from the point of view of education and giving the skills to the engineers and from there upwards? (I3) yes I honestly think it needs to come from the institutions first off the coherent set of standards then the educational establishment can take and develop into courses and modules or things like that, to align them to sustainable technology and then take it a step at a time in the development into the built environment but certainly starting off with the institutions then the education establishments in parallel with some government funding for research which then the universities and institutions can participate that is how I would like to see delivered.

17. Is enough information out there at this time to make a standard, or does research have to come in before a standard? (I3) I think there's enough out there for the standard, there are some good European documents at the moment that can be reworked in terms of

developing DC standards all be it these are regulations we still need standards to support the regulations we seem to have got ourselves round the wrong way, we seem to have developed some good regulations already but haven't developed a coherent set of standards.

18. Do you think that the government is doing enough to help to the proliferation DC system? (I3) no, I don't think it is doing anything.

### **SECTION 3: REFLECT ON THE INTERVIEW AND CLOSE**

1. Do you now intend to further develop the use of DC voltage within your organisation, do you see it coming to fruition? (I3) I think it will eventually but it will need some examples to be deployed and some test cases to be deployed.

2. Have you looked at data centres in Americans that are using DC backbones etc? (I3) yes I have looked at those, I have looked at some in Sweden so some of the colocation data centres are actually using DC power now

3. Are those therefore up to the understand that you will be looking for? (I3) no I had not specifically seen them on-site and I am led to believe that they are designed to what they believe is the stand which will be adopted

4. In five years' time do you think that more of your organisation will use DC voltage voltages? (I3) in the data centres I think it will be inevitable conclusion that we will need to move to, to take the last savings that we possibly can

5. What about out of the data centre into the workplace? (I3) into the workplace I think it will take a little bit longer because I don't think we have the final distribution to the desk or socket outlet specifically designed yet.

6. What do you think maybe different in 5 years time - the technologies, regulations, what people want as end users etc? (I3) in five years' time I see the power load in the workplace reducing significantly to the point that DC power will become a viable option because we won't need to be distributing large kilowatts of energy around buildings we will be relying more on laptops hopefully with batteries that will last a full day and as people start to use intelligent working and hot desking and stuff like that they will moving in-between buildings therefore we won't need to see masses and masses of power at the desk for instance DC power in terms of DC lighting DC within data centres which support these mobile devices will in my opinion be takeover

7. With regards to DC in the home and higher power like microwaves and heating water etc what you think that will look like in five years' time? (I3) I'm not convinced it will get to the home any time soon I think that homeowners are a different sort of human interface to the household infrastructure and I think that they are now confident to use AC understand it trying to bring in DC power and the necessity to have some voltage change, because you always need A/C power in the house, so why would you want to do that in household where the occupants may not even be technically orientated whatsoever so that there will need to be a robustness in that system that is fail proof and does not need any human interface whatsoever but we know that that will never be the case I would suggest that the DC domestic market is a long way off despite having PV on the roofs and things like that I think



that will be 10 to 15 years away at least before we get new homes that are constructed with pure DC only.

8. Do you see the same pathway infrastructure as being the same hurdles for the home as it is with the office? (I3) I think the office environment is much more controlled environment a much more managed maintained environment the home isn't so I not sure I can comment any further on that on the basis that domestic households would not want to complicate the buildings unnecessarily by inclusion of a DC system with A/C system they will want one system and that's it.

9. Are there any comments or issues you would like to add or discuss from the interview or the research project? (I3) I don't think so at this time I like to see more of it as it develops other interested in it.

**Appendix 5 Journal paper “*To what extent is electricity central to resilience and disaster management of the built environment?*”**